## 4.1 GENERAL DESIGN CONSIDERATIONS

Wind with sufficient speed to cause damage to weak hospitals can occur anywhere in the United States and its territories.[1] Even a well-designed, constructed, and maintained hospital may be damaged by a wind event much stronger than one the building was designed for. However, except for tornado damage, this scenario is a rare occurrence. Rather, most damage occurs because various building elements have limited wind resistance due to inadequate design, poor installation, or material deterioration. Although the magnitude and frequency of strong windstorms vary by locale, all hospitals should be designed, constructed, and maintained to minimize wind damage (other than that associated with tornadoes —see Section 4.5).

This chapter discusses structural, building envelope, and nonstructural building systems, and illustrates various types of wind-induced damage that affect them. It also presents six case studies. Numerous examples of best practices pertaining to new and existing hospitals are presented as recommended design guidelines. Incorporating those practices applicable to specific projects will result in greater wind-resistance reliability and will, therefore, decrease expenditures for repair of wind-damaged facilities, provide enhanced protection for occupants, and avoid disruption of critical services.

The recommendations presented in this manual are based on field observation research conducted on 25 hospitals that were struck by

1 The U.S. territories include American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the U.S. Virgin Islands. ASCE 7 provides basic wind speed criteria for all but Northern Mariana Islands.

hurricanes[2]. The recommendations are also based on numerous investigations of other types of critical facilities and other types of buildings exposed to hurricanes and tornadoes, and on literature review. Some of the 25 hospitals were exposed to extremely high wind speeds, while others experienced moderate speeds. Approximately 88 percent of the 25 hospitals experienced roof covering damage (many of which also experienced damage to rooftop equipment), and windows were broken on approximately 50 percent of them. Because of wind damage and subsequent water leakage, one of the hospitals was totally evacuated after a hurricane (Figure 4-1). Another hospital was also evacuated after a hurricane, but evacuation was prompted by flooding. Five other hospitals were partially evacuated after the storm because of interior water damage. None of the main hospital buildings on these 25 campuses experienced structural failure, although a few auxiliary buildings did collapse.

**Figure 4-1:** Deering Hospital was evacuated after Hurricane Andrew due to water infiltration caused by roof covering, window, and door damage.

The 200-bed Deering Hospital opened shortly before Hurricane Andrew struck south Florida in 1992. Aggregate from the hospital's built-up roofs broke several windows, the roof covering was blown off in some areas (Figure 4-9), and the entrance doors at the emergency room were blown away. Because of extensive interior water damage, the entire hospital was evacuated after the storm and remained closed for 9 months.

2 The research on the 25 hospitals was conducted by a team from Texas Tech University (Hurricane Hugo, Charleston, South Carolina, 1989), a team under the auspices of the Wind Engineering Research Council—now known as the American Association for Wind Engineering (Hurricane Andrew, South Florida, 1992), and teams deployed by FEMA (Hurricane Marilyn, U.S. Virgin Islands, 1995; Typhoon Paka, Guam, 1997; Hurricane Charley, Port Charlotte, Florida, 2004; Hurricane Frances, east coast of Florida, 2004, Hurricane Ivan, Pensacola, Florida, 2004; and Hurricane Katrina, Louisiana and Mississippi, 2005).

## 4.1.1 NATURE OF HIGH WINDS

A variety of windstorm types occur in different areas of the United States. The characteristics of the types of storms that can affect the site should be considered by the design team. The primary storm types are straight-line winds, down-slope winds, thunderstorms, downbursts, northeasters (nor'easters), hurricanes, and tornadoes. For information on these storm types, refer to Section 3.1.1 in FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*.[3]

Of all the storm types, hurricanes have the greatest potential for devastating a large geographical area and, hence, affect the greatest number of people. See Figure 4-2 for hurricane-prone regions.

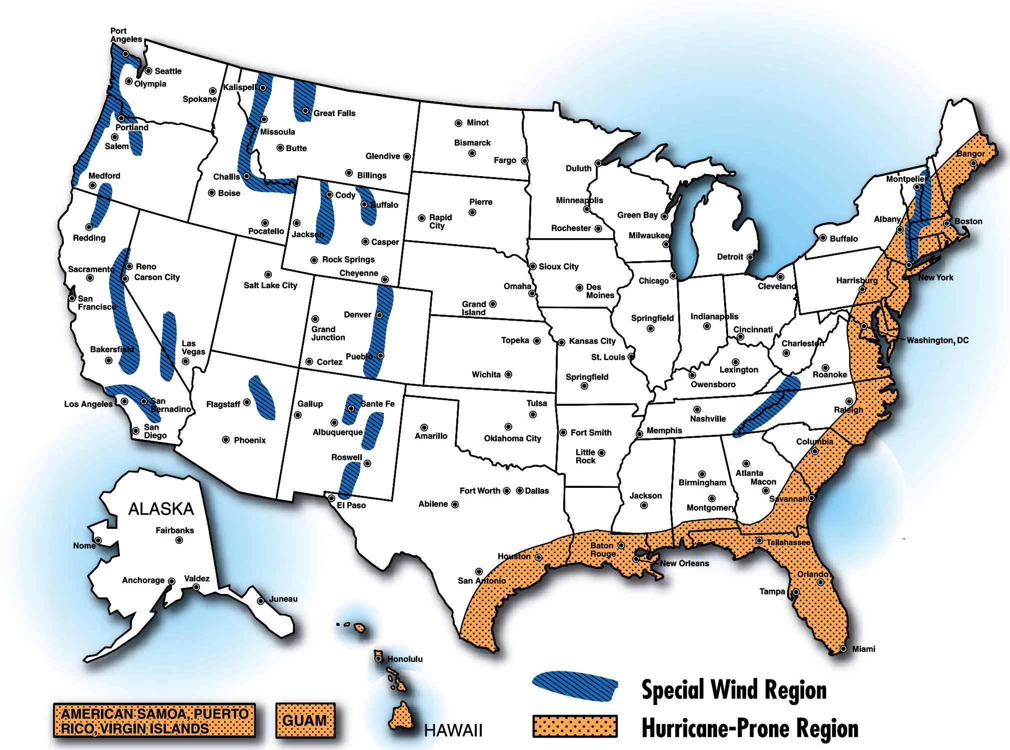



Figure 4-2: Hurricane-prone regions and special wind regions

SOURCE: ADAPTED FROM ASCE 7-05

## 4.1.2 PROBABILITY OF OCCURRENCE

Via the importance factor,[4] ASCE 7 requires Category III and IV buildings to be designed for higher wind loads than Category I and II buildings. Hence, hospitals designed in accordance with ASCE 7 have greater

3 Available at the FEMA Web site. See www.fema.gov/library/viewRecord.do?id=2441

4 The importance factor accounts for the degree of hazard to human life and damage to property. Importance factors are given in ASCE 7.

resistance to stronger, rarer storms. When designing a hospital, design professionals should consider the following types of winds.

**Routine winds:** In many locations, winds with low to moderate speeds occur daily. Damage is not expected to occur during these events.

> Missile damage is very common during hurricanes and tornadoes. Missiles can puncture roof coverings, many types of exterior walls, and glazing. The IBC does not address missile-induced damage, except for glazing in wind-borne debris regions. (Wind-borne debris regions are limited to portions of hurricane-prone regions.) In hurricane-prone regions, significant missile-induced building damage should be expected, even during design level hurricane events, unless special enhancements are incorporated into the building's design (discussed in Section 4.3).

**Stronger winds:** At a given site, stronger winds (i.e., winds with a speed in the range of 70 to 80 mph peak gust, measured at 33 feet in Exposure C—refer to Section 4.1.3) may occur from several times a year to only once a year or even less frequently. This is the threshold at which damage normally begins to occur to building elements that have limited wind resistance due to problems associated with inadequate design, insufficient strength, poor installation, or material deterioration.

**Design level winds:** Hospitals exposed to design level events and events that are somewhat in excess of design level should experience little, if any, damage. Actual storm history, however, has shown that design level storms frequently cause extensive building envelope damage. Structural damage also occurs, but less frequently. Damage incurred in design level events is typically associated with inadequate design, poor installation, or material deterioration. The exceptions are wind-driven water infiltration and wind-borne debris (missiles) damage. Water infiltration is discussed in Sections 4.3.3.1, 4.3.3.3, and 4.3.3.5.

> ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, provides guidance for determining wind loads on buildings. The IBC and NFPA 5000 refer to ASCE 7 for wind load determination.

**Tornadoes:** Although more than 1,200 tornadoes typically occur each year in the United States, the probability of a tornado occurring at any given location is quite small. The probability of occurrence is a function of location. As described in Section 4.5, only a few areas of the country frequently experience tornadoes, and tornadoes are very rare in the west. The Oklahoma City area is the most active location, with 112 recorded tornadoes between 1890 and 2003 (www.spc.noaa.gov/faq/tornado/#History).

Well-designed, constructed, and maintained hospitals should experience little if any damage from weak tornadoes, except for window breakage. However, weak tornadoes often cause building envelope damage because of wind-resistance deficiencies. Most hospitals experience significant damage if they are in the path of a strong or violent tornado because they typically are not designed for this type of storm. See Section 4.5 for recommendations pertaining to tornadoes.

### 4.1.3 WIND/BUILDING INTERACTIONS

When wind interacts with a building, both positive and negative (i.e., suction) pressures occur simultaneously. Hospitals must have sufficient strength to resist the applied loads from these pressures to prevent wind-induced building failure. Loads exerted on the building envelope are transferred to the structural system, where in turn they must be transferred through the foundation into the ground. The magnitude of the pressures is a function of the following primary factors: exposure, basic wind speed, topography, building height, internal pressure, and building shape. For general information on these factors, refer to Section 3.1.3 in FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*. A description of key issues follows.

**Wind Speed:** In the ASCE 7 formula for determining wind pressures, the basic wind speed is squared. Therefore, as the wind speed increases, the pressures are exponentially increased, as illustrated in Figure 4-3. This figure also illustrates the relative difference in pressures exerted on the main wind-force resisting system (MWFRS) and the components and cladding (C&C) elements.

> The MWFRS is an assemblage of structural elements assigned to provide support and stability for the overall structure. The system generally receives wind loading from more than one surface. The C&C are elements of the building envelope that do not qualify as part of the main wind-force resisting system.

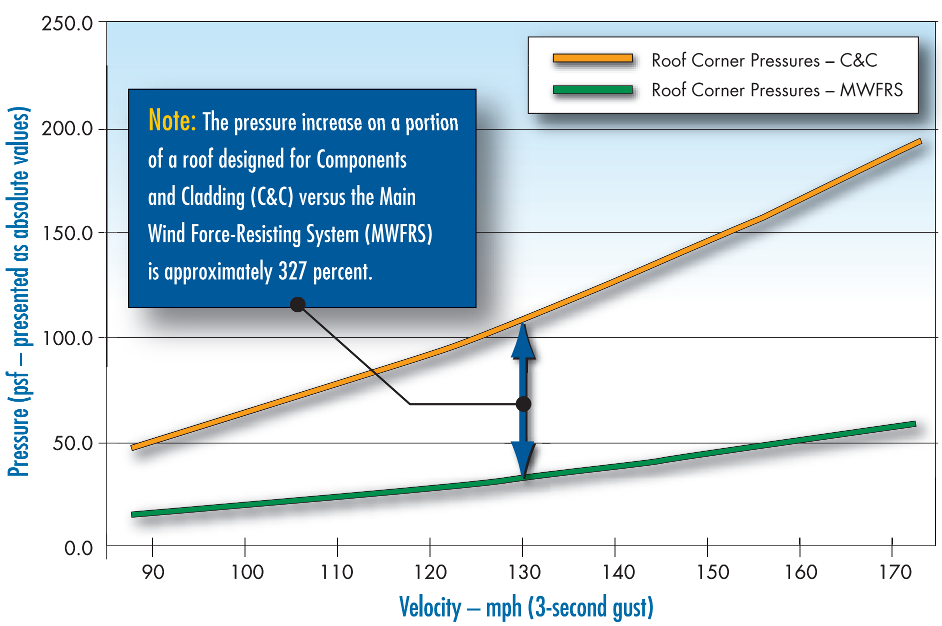
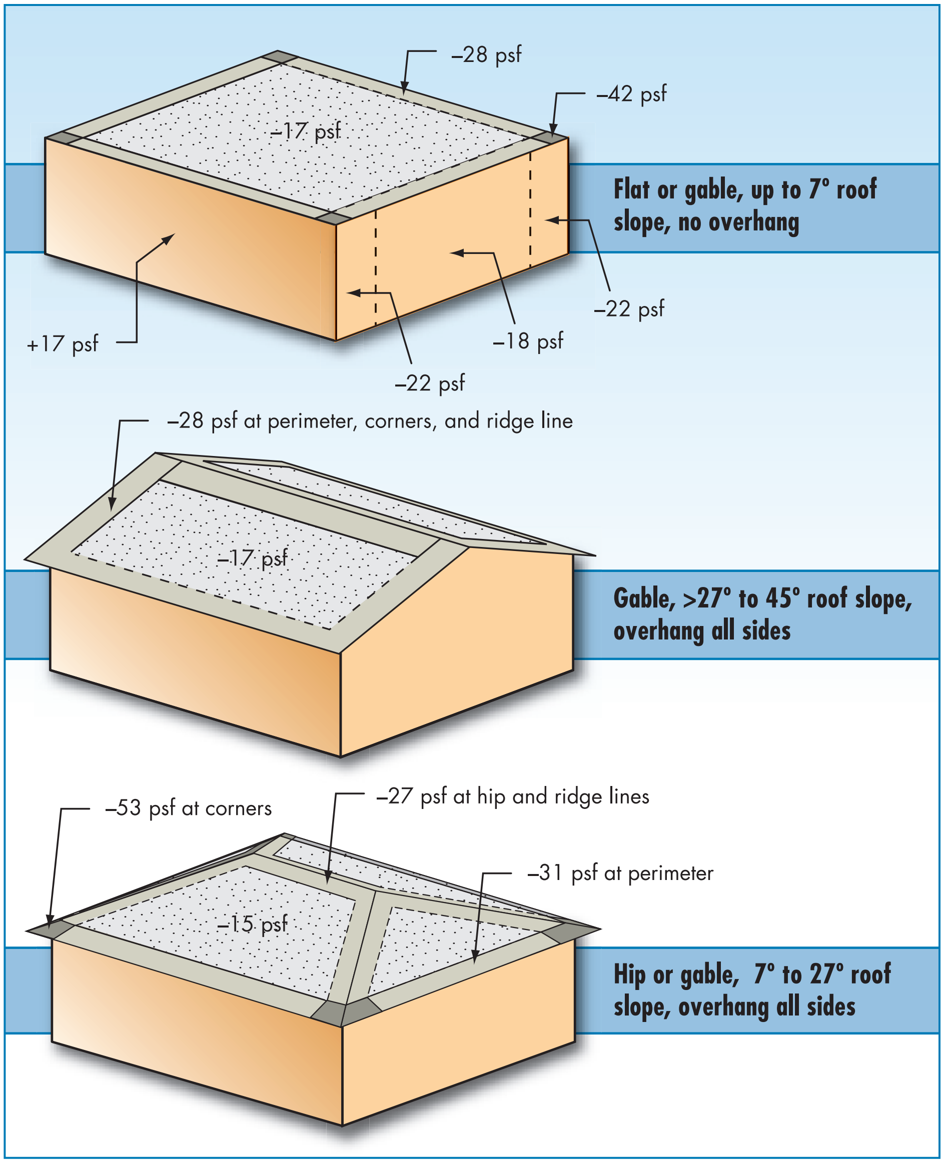



**Figure 4-3:** Wind pressure as a function of wind speed

**Building shape:** The highest uplift pressures occur at roof corners because of building aerodynamics (i.e., the interaction between the wind and the building). The roof perimeter has a somewhat lower load compared to the corners, and the field of the roof has still lower loads. Exterior walls typically have lower loads than the roof. The ends (edges) of walls have higher suction loads than the portion of wall between the ends. However, when the wall is loaded with positive pressure, the entire wall is uniformly loaded. Figure 4-4 illustrates these aerodynamic influences. The negative values shown in Figure 4-4 indicate suction pressure acting upward from the roof surface and outward from the wall surface. Positive values indicate positive pressure acting inward on the wall surface.

Figure 4-4:
Relative roof uplift pressures as a function of roof geometry, roof slope, and location on roof, and relative positive and negative wall pressures as a function of location along the wall



Aerodynamic influences are accounted for by using external pressure coefficients in load calculations. The value of the coefficient is a function of the location on the building (e.g., roof corner or field of roof) and building shape as discussed below. Positive coefficients represent a positive (inward-acting) pressure, and negative coefficients represent negative (outward-acting [suction]) pressure. External pressure coefficients for MWFRS and C&C are listed in ASCE 7.

Building shape affects the value of pressure coefficients and, therefore, the loads applied to the various building surfaces. For example, the uplift loads on a low-slope roof are larger than the loads on a gable or hip roof. The steeper the slope, the lower the uplift load. Pressure coefficients for monoslope (shed) roofs, sawtooth roofs, and domes are all different from those for low-slope and gable/hip roofs.

Building irregularities, such as re-entrant corners, bay window projections, a stair tower projecting out from the main wall, dormers, and chimneys can cause localized turbulence. Turbulence causes wind speed-up, which increases the wind loads in the vicinity of the building irregularity, as shown in Figures 4-5 and 4-6. Figure 4-5 shows the aggregate ballast on a hospital's single-ply membrane roof blown away at the re-entrant corner and in the vicinity of the corners of the wall projections at the window bays. The irregular wall surface created turbulence, which led to wind speed-up and loss of aggregate in the turbulent flow areas.

Figure 4-6 shows a stair tower at a hospital that caused turbulence resulting in wind speed-up. The speed-up increased the suction pressure on the base flashing along the parapet behind the stair tower. The built-up roof's base flashing was pulled out from underneath the coping because its attachment was insufficient to resist the suction pressure. The base flashing failure propagated and caused a large area of the roof membrane to lift and peel. Some of the wall covering on the stair tower was also blown away. Had the stair tower not existed, the built-up roof would likely not have been damaged. To avoid damage in the vicinity of building irregularities, attention needs to be given to the attachment of building elements located in turbulent flow areas.

To avoid the roof membrane damage shown in Figure 4-6, it would be prudent to use corner uplift loads in lieu of perimeter uplift loads in the vicinity of the stair tower, as illustrated in Figure 4-7. Wind load increases due to building irregularities can be identified by wind tunnel studies; however, wind tunnel studies are rarely performed for hospitals. Therefore, identification of wind load increases due to building

> Information pertaining to load calculations is presented in Section 4.3.1.2. For further general information on the nature of wind and wind-building interactions, see *Buildings at Risk: Wind Design Basics for Practicing Architects,* American Institute of Architects, 1997.

irregularities will normally be based on the designer's professional judgment. Usually load increases will only need to be applied to the building envelope, and not to the MWFRS.

**Figure 4-5:** Aggregate blow-off associated with building irregularities. Hurricane Hugo (South Carolina, 1989)

**Figure 4-6:** The irregularity created by the stair tower (covered with a metal roof) caused turbulence resulting in wind speed-up and roof damage. Hurricane Andrew (Florida, 1992)

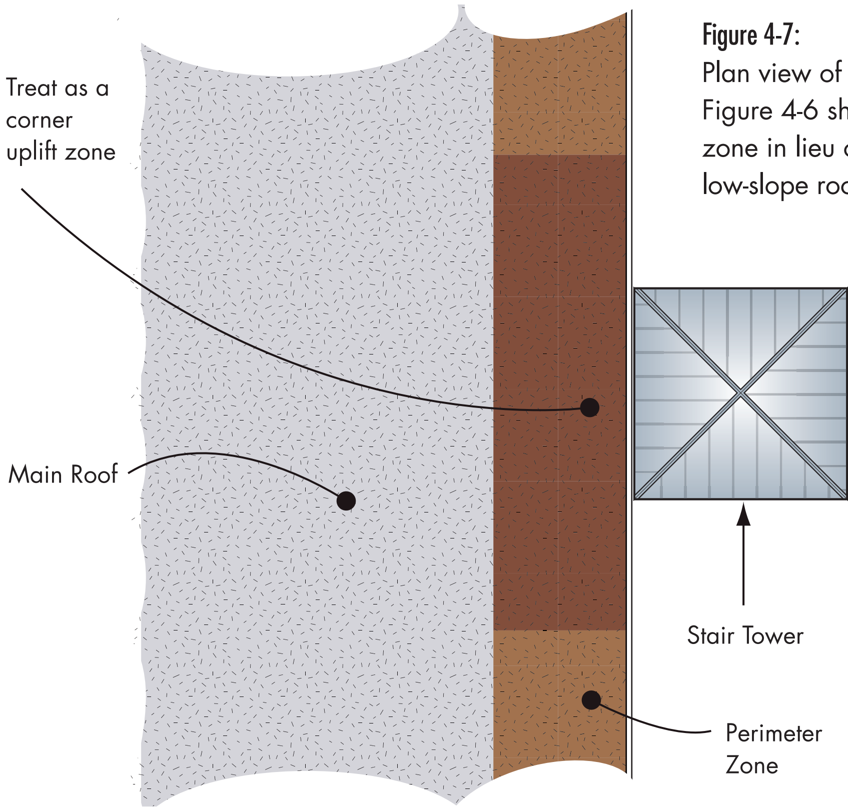



**Figure 4-7:**
Plan view of a portion of the building in Figure 4-6 showing the use of a corner uplift zone in lieu of a perimeter uplift zone on the low-slope roof in the vicinity of the stair tower

## 4.1.4 BUILDING CODES

The IBC is the most extensively used model code. However, in some jurisdictions NFPA 5000 may be used. In other jurisdictions, one of the earlier model building codes, or a specially written State or local building code, may be used. The specific scope and/or effectiveness and limitations of these other building codes will be somewhat different from those of the IBC. It is incumbent upon the design professionals to be aware of the specific code (including the edition of the code and local amendments) that has been adopted by the authority having jurisdiction over the location of the hospital.

### 4.1.4.1 Scope of Building Codes

With respect to wind performance, the scope of the model building codes has greatly expanded since the mid-1980s. Some of the most significant improvements are discussed below.

**Recognition of increased uplift loads at the roof perimeter and corners:** Prior to the 1982 edition of the Standard Building Code (SBC), Uniform Building Code (UBC), and the 1987 edition of the National Building Code (NBC), these model codes did not account for the increased uplift at the roof perimeter and corners. Therefore, hospitals designed in accordance with earlier editions of these codes are very susceptible to blow-off of the roof deck and/or roof covering.

**Adoption of ASCE 7 for design wind loads:** Although the SBC, UBC, and NBC permitted use of ASCE 7, the 2000 edition of the IBC was the first model code to require ASCE 7 for determining wind design loads on all buildings. ASCE 7 has been more reflective of the current state of the knowledge than the earlier model codes, and use of this procedure typically has resulted in higher design loads.

**Roof coverings:** Several performance and prescriptive requirements pertaining to wind resistance of roof coverings have been incorporated into the model codes. The majority of these additional provisions were added after Hurricanes Hugo (1989) and Andrew (1992). Poor performance of roof coverings was widespread in both of those storms. Prior to the 1991 edition of the SBC and UBC, and the 1990 edition of the NBC, these model codes were essentially silent on roof covering wind loads and test methods for determining uplift resistance. Code improvements continued to be made through the 2006 edition of the IBC, which added a provision that prohibits aggregate roof surfaces in hurricane-prone regions.

> ASCE 7 requires impact-resistant glazing in wind-borne debris regions within hurricane-prone regions. Impact-resistant glazing can either be laminated glass, polycarbonate, or shutters tested in accordance with standards specified in ASCE 7. The wind-borne debris load criteria were developed to minimize property damage and to improve building performance. The criteria were not developed for occupant protection. Where occupant protection is a specific criterion, the more conservative wind-borne debris criteria given in FEMA 361, *Design and Construction Guidance for Community Shelters* is recommended.

**Glazing protection:** The 2000 edition of the IBC was the first model code to address wind-borne debris requirements for glazing in buildings located in hurricane-prone regions (via reference to the 1998 edition of ASCE 7). The 1995 edition of ASCE 7 was the first edition to address wind-borne debris requirements.

**Parapets and rooftop equipment:** The 2003 edition of the IBC was the first model code to address wind loads on parapets and rooftop equipment (via reference to the 2002 edition of ASCE 7, which was the first edition of ASCE 7 to address these elements).

### 4.1.4.2 Effectiveness and Limitations of Building Codes

A key element of an effective building code is for a community to have an effective building department. Building safety depends on more than the codes and the standards they reference. Building safety results when trained professionals have the resources and ongoing support they need to stay on top of the latest advancements in building safety. An effective building safety system provides uniform code interpretations, product evaluations, and professional development and certification for inspectors and plan reviewers. Local building departments play an important role in helping to ensure buildings are designed and constructed in accordance with the applicable building codes. Meaningful plan review and inspection by the building department are particularly important for hospitals.

General limitations to building codes include the following:

- Because codes are adopted and enforced on the local or State level, the authority having jurisdiction has the power to eliminate or modify wind-related provisions of a model code, or write its own code instead. In places where important wind-related provisions of the current model code are not adopted and enforced, hospitals are more susceptible to wind damage. Additionally, a significant time lag often exists between the time a model code is updated and the time it is implemented by the authority having jurisdiction. Buildings designed to the minimum requirements of an outdated code are, therefore, not taking advantage of the current state of the knowledge. These buildings are prone to poorer wind performance compared to buildings designed according to the current model code.

- Adopting the current model code alone does not ensure good wind performance. The code is a minimum that should be used by knowledgeable design professionals in conjunction with their training, skills, professional judgment, and the best practices presented in this manual. To achieve good wind performance, in addition to good design, the construction work must be effectively executed, and the building must be adequately maintained and repaired.

- Hospitals need to perform at a higher level than required by codes and standards.

**IBC 2006:** The 2006 edition of the IBC is believed to be a relatively effective code, provided that it is properly followed and enforced. Some limitations of the 2006 IBC have, however, been identified:

- With respect to hurricanes, the IBC provisions pertaining to building envelopes and rooftop equipment do not adequately address the special needs of hospitals. For example: (1) they do not account for water infiltration due to puncture of the roof membrane by missiles; (2) they do not adequately address the vulnerabilities of brittle roof coverings (such as tile) to missile-induced damage and subsequent progressive failure; (3) they do not adequately address occupant protection with respect to missiles; (4) they do not adequately address protection of equipment in elevator penthouses; and (5) they do not account for interruption of water service or prolonged interruption of electrical power. All of these elements are of extreme importance for hospitals, which need to remain operational before, during, and after a disaster. Guidance to overcome these shortcomings is given in Section 4.3 and 4.4.

- The 2000, 2003, and 2006 IBC rely on several referenced standards and test methods developed or updated in the 1990s. Prior to adoption, most of these standards and test methods had not been validated by actual building performance during design level wind events. The hurricanes of 2004 and 2005 provided an opportunity to evaluate the actual performance of buildings designed and constructed to the minimum provisions of the IBC. Building performance evaluations conducted by FEMA revealed the need for further enhancements to the 2006 IBC pertaining to some of the test methods used to assess wind and wind-driven rain resistance of building envelope components. For example, there is no test method to assess wind resistance of gutters. Further, the test method to evaluate the resistance of windows to wind-driven rain is inadequate for high wind events. However, before testing limitations can be overcome, research needs to be conducted, new test methods need to be developed, and some existing test methods need to be modified.

- Except to the extent covered by reference to ASCE 7, the 2006 IBC does not address the requirement for continuity, redundancy, or energy-dissipating capability (ductility) to limit the effects of local collapse, and to prevent or minimize progressive collapse after the loss of one or two primary structural members, such as a column. Chapter 1 of ASCE 7 addresses general structural integrity, and the Chapter 1 Commentary provides some guidance on this issue.

- The 2006 IBC does not account for tornadoes; therefore, except for weak tornadoes, it is ineffective for this type of storm.[5] Guidance to overcome this shortcoming is given in Section 4.5.

5 Except for glass breakage, code-compliant buildings should not experience significant damage during weak tornadoes.

# 4.2 HOSPITALS EXPOSED TO HIGH WINDS

## 4.2.1 VULNERABILITY: WHAT HIGH WINDS CAN DO TO HOSPITALS

This section provides an overview of the common types of wind damage and their ramifications.

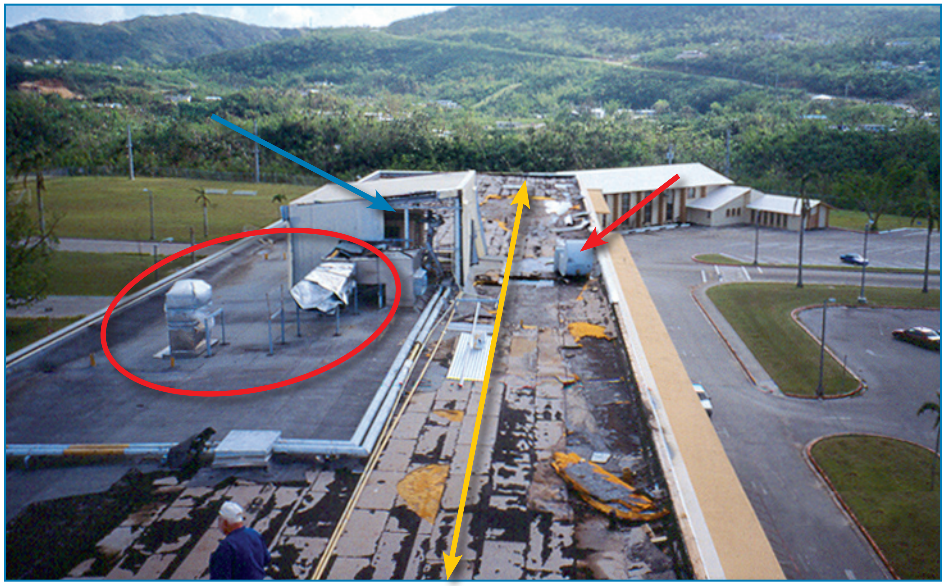
### 4.2.1.1 Types of Building Damage

When damaged by wind, hospitals typically experience a variety of building component damage. For example, at the hospital shown in Figure 4-8, the roof covering was severely damaged, windows were broken, and rooftop equipment was blown away. The subsequent water infiltration required that most of the hospital be evacuated. The most common types of damage are discussed below in descending order of frequency.

**Figure 4-8:**
Field military hospital in tents set up to replace evacuated hospital in U.S. Virgin Islands following Hurricane Marilyn (1995)

**Roof:** Roof covering damage (including rooftop mechanical, electrical, and communications equipment) is the most common type of wind damage, as illustrated by Figure 4-9. In addition to blowoff of the roof membrane (yellow arrow), ductwork blew away (red circle), a gooseneck was blown over (red arrow), and wall panels at an equipment enclosure were blown off (blue arrow). The cast-in-place concrete deck kept most of the water from entering the hospital.

**Figure 4-9:** Damaged roof membrane and rooftop equipment. Typhoon Paka (1997)



**Glazing:** Exterior glazing damage is very common during hurricanes and tornadoes, but is less common during other storms. The glass shown in Figure 4-10 was broken by the aggregate from a built-up roof. The inner panes had several impact craters. In several of the adjacent windows, both the outer and inner panes were broken. The aggregate flew more than 245 feet (the estimated wind speed was 104 mph, measured at 33 feet in Exposure C).

**Figure 4-10:** The outer window panes were broken by aggregate from a built-up roof. Hurricane Hugo (South Carolina, 1989)

**Wall coverings, soffits, and large doors:** Exterior wall covering, soffit, and large door damage is common during hurricanes and tornadoes, but is less common during other storms. Wall covering damage is shown at the hospital complex described in the West Florida Hospital case study, Section 4.1.3.

**Wall collapse:** Collapse of non-load-bearing exterior walls is common during hurricanes and tornadoes, but is less common during other storms. At the hospital shown in Figure 4-11, a portion of the non-load-bearing wall collapsed. Several windows were also broken by aggregate ballast blown from the hospital's roof (see Figure 4-5).

**Figure 4-11:** Collapse of non-load-bearing wall (red circle) and broken glazing from roof aggregate (red arrow). Hurricane Hugo (South Carolina, 1989)

**Structural system:** Structural damage (e.g., roof deck blow-off, blow-off or collapse of the roof structure, collapse of exterior bearing walls, or collapse of the entire building or major portions thereof) is the principal type of damage that occurs during strong and violent tornadoes (see Figure 4-12)
.

**Figure 4-12:** This building in Northern Illinois was heavily damaged by a strong tornado in 1990.

### 4.2.1.2 Ramifications of Damage

The ramifications of building component damage on hospitals are described below.

**Property damage:** Property damage requires repairing/replacing the damaged components (or replacing the entire facility), and may require repairing/replacing interior building components, furniture, and other equipment, and mold remediation. As illustrated by Figures 4-1 and 4-8, even when damage to the building envelope is limited, such as blow-off of a portion of the roof covering or broken glazing, substantial water damage frequently occurs because heavy rains often accompany strong winds (particularly in the case of thunderstorms, tropical storms, hurricanes, and tornadoes).

Wind-borne debris such as roof aggregate, gutters, rooftop equipment, and siding blown from buildings can damage vehicles and other buildings in the vicinity. Debris can travel well over 300 feet in high-wind events.

> Modest wind speeds can drive rain into exterior walls. Unless adequate provisions are taken to account for water infiltration (see Sections 4.3.3.1 – 4.3.3.6), damaging corrosion, dry rot, and mold can occur within walls.

Ancillary buildings (such as storage buildings) adjacent to hospitals are also vulnerable to damage. Although loss of these buildings may not be crippling to the operation of the hospital, debris from ancillary buildings may strike and damage the hospital.

**Injury or death:** Although infrequent, hospital occupants or people outside hospitals may be injured and killed if struck by collapsed building components (such as exterior masonry walls or the roof structure) or wind-borne debris. The greatest risk of injury or death is during strong hurricanes and strong/violent tornadoes. If a hospital, or a portion of a hospital, needs to be evacuated due to wind-related damage, patients may be exposed to risk of injury or death during their relocation.

**Interrupted use:** Depending on the magnitude of wind and water damage, it can take days, months, or more than a year to repair the damage or replace a facility. In addition to the costs associated with repairing/replacing the damage, other social and financial costs can be even more significant. The repercussions related to interrupted use of hospitals can include lack of medical care, and the costs to rent temporary facilities. These additional costs can be quite substantial.

> Although people are not usually outside during hurricanes, it is not uncommon for people to seek medical care during a storm. Missiles, such as roof aggregate or tile shedding from a hospital, could injure or kill people before they have a chance to enter the building.

### 4.2.1.3 The Case of West Florida Hospital, Pensacola, Florida

The case of West Florida Hospital illustrates a variety of building performance problems. The 531-bed West Florida Healthcare facility (also called the Pavillion) includes the 400-bed acute tertiary West Florida Hospital, the 58-bed Rehabilitation Institute, and a 73-bed behavioral health facility. The Pavillion is located north of downtown Pensacola, approximately 3 miles west of Escambia Bay and 7 miles north of Pensacola Bay. West Florida was struck by Hurricane Ivan in 2004. The estimated peak gust wind speed at this site was 105 to 115 mph.[6] The design wind speed in the 2005 edition of ASCE 7 for this location is 135 mph.

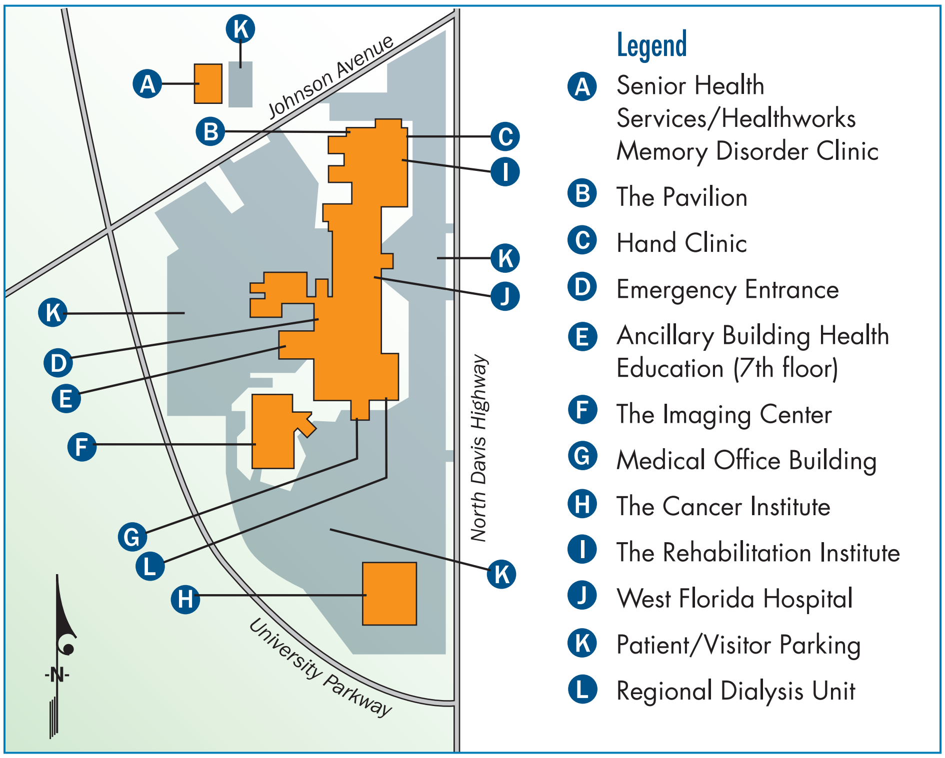



**Figure 4-13:** Site plan

The West Florida Hospital (J on Figure 4-13) and several of the other buildings on the campus experienced a variety of damages during the storm. The roof membrane was punctured in several places by windborne missiles and by damaged rooftop equipment (see Figures 4-14 to 4-16).

Exterior insulation finish system (EIFS) blew off the hospital and caused significant glass breakage in the MOB (Figure 4-17) and the walkway connecting the hospital to the MOB. Some of the lower-level windows may have been broken by wind-blown aggregate ballast from the roof over the dialysis unit and urgent care facility. In addition, some window frames

6 The 105 to 1115 mph speeds were estimated for Exposure C.

were reportedly blown out. These failures were likely caused by the development of high internal pressure after windows on windward surfaces were broken by missiles, combined with suction pressure on the exterior surface of windows on the leeward side of the building. Glass damage to the MOB, and subsequent wind and water damage to the interior, resulted in closure of several offices.

In addition to the window breakage, EIFS blew off the elevator enclosure, the stair tower, and the spandrels. The single-ply roof membrane was damaged and the Lightning Protection System (LPS) on the MOB was also displaced.

The hospital originally had exposed concrete walls. However, in a subsequent refurbishing, the walls were faced with EIFS. Steel hat channels were installed over the concrete, followed by gypsum board, insulation, and synthetic stucco. In areas where the EIFS blew off, the gypsum board typically pulled over the screw heads and blew away (Figure 4-23). The screws and hat channels were moderately corroded. Although the corrosion could have eventually caused loss of the EIFS, it did not play a role in this failure.

With loss of the EIFS wall covering, wind-driven rain destroyed the elevator control equipment (see Figure 4-22). Water damage to the elevator control equipment resulted in failure of the MOB stair tower elevator. As a result, several people were trapped in the MOB stair tower elevator shown in Figure 4-18 during the hurricane. Fortunately, the MOB had another bank of elevators in the core of the building that was not damaged, so vertical transportation was still possible, although handicapped by the loss of the stair tower elevator. At the MOB stair tower, some of the gypsum board on the interior side of the studs collapsed into the stairway, thus trapping a maintenance worker who had gone to the mechanical penthouse during the hurricane.

Glass shards from the MOB punctured the ballasted single-ply membrane over the regional dialysis unit and urgent care facility (item L on Figure 4-13). Although the roof membrane had been punctured in numerous areas (Figure 4-20), the concrete deck (concrete topping over metal decking) over the dialysis unit and urgent care facility acted as an secondary line of protection against water leakage and was effective in minimizing water infiltration into the facility, thereby minimizing interrupted use of these facilities. By quickly performing emergency roof repairs and cleaning up the interior, the dialysis unit was non-operational for only 1 day.

At the cancer treatment facility (H on Figure 4-13), asphalt shingles were blown from the roof hips and some eave edge metal lifted. Additionally, sewage backed up at this facility because of power loss to a lift station. Sewage backup was cleaned up quickly and the facility was non-operational for only 1 day.

At the imaging center (F on Figure 4-13), there were some broken windows and a fan cowling blew away. Some large parking lot light fixtures also collapsed because the bottoms of the tubes were severely corroded (Figure 4-21).

Communications outside of the hospital were lost about an hour after the arrival of high winds because of damage to the communications antenna; the LPS was also displaced (Figure 4-15). A canopy at the loading dock was blown away, which caused difficulties in materials handling.

Because of rapid emergency response by construction and clean-up crews, the hospital and other facilities on campus remained functional. However, the damage was very costly and created many hardships for hospital staff.

**Figure 4-14:** Numerous repairs where the modified bitumen roof membrane was punctured by missiles. Water from the punctured membrane entered the surgical suite.

Figure 4-15: Damaged rooftop equipment (red arrows), collapsed antenna (circled), and displaced LPS (yellow arrows)

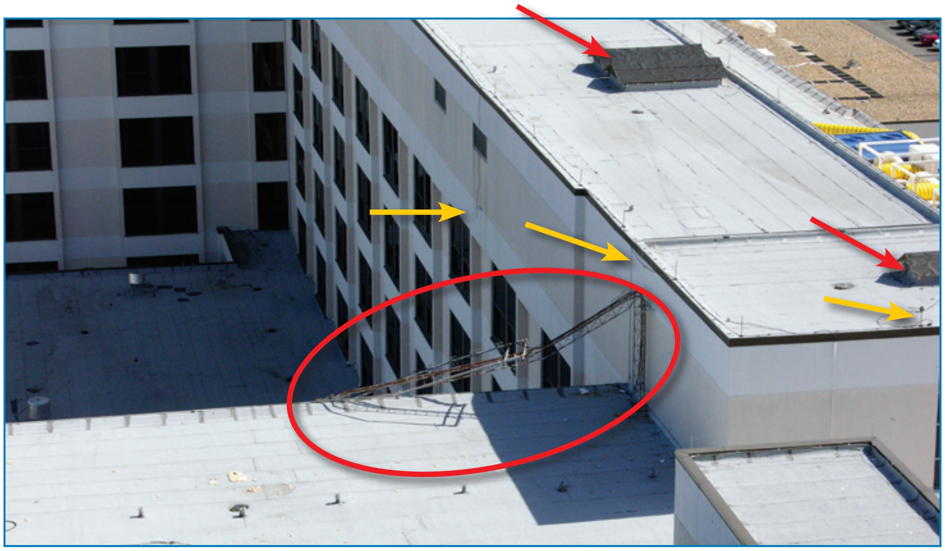


Figure 4-16: Damaged rooftop equipment. Although some of this damage may have been caused by wind pressure, some of it was caused by missiles. Note the open ducts (red arrows).

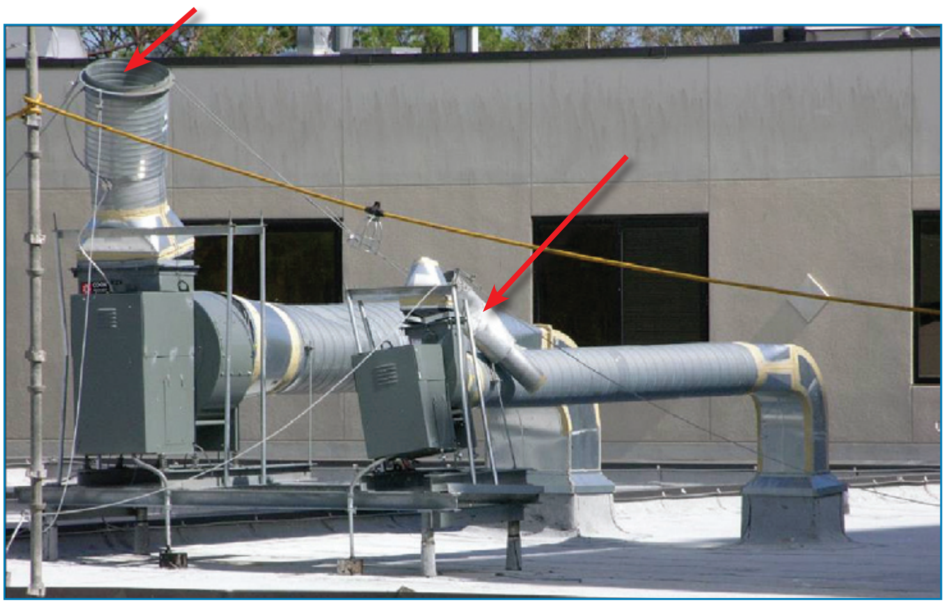


Figure 4-17: Broken windows in the MOB. Wood studs and gypsum board had been temporarily installed after the hurricane to prevent patients from inadvertently falling out of the MOB.

**Figure 4-18:**
Broken windows in the connecting walkway between the hospital (right) and MOB (left) (red arrow). Also note the broken windows and loss of EIFS (including the gypsum board on both sides of the studs) at the elevator enclosure (blue arrow).

**Figure 4-19:**
EIFS debris blown off the hospital building (Item J on Figure 4-13) in the background (red square) broke numerous windows in the MOB (item G on figure 4-13) in the foreground.

Figure 4-20:
Looking down at the one-story roof to the right of the MOB in Figure 4-19. The small dark areas are locations where emergency patches had been placed to repair punctures from falling glass shards. (Note: At the time the photo was taken, the ballast had been repositioned into rows in preparation for removal)

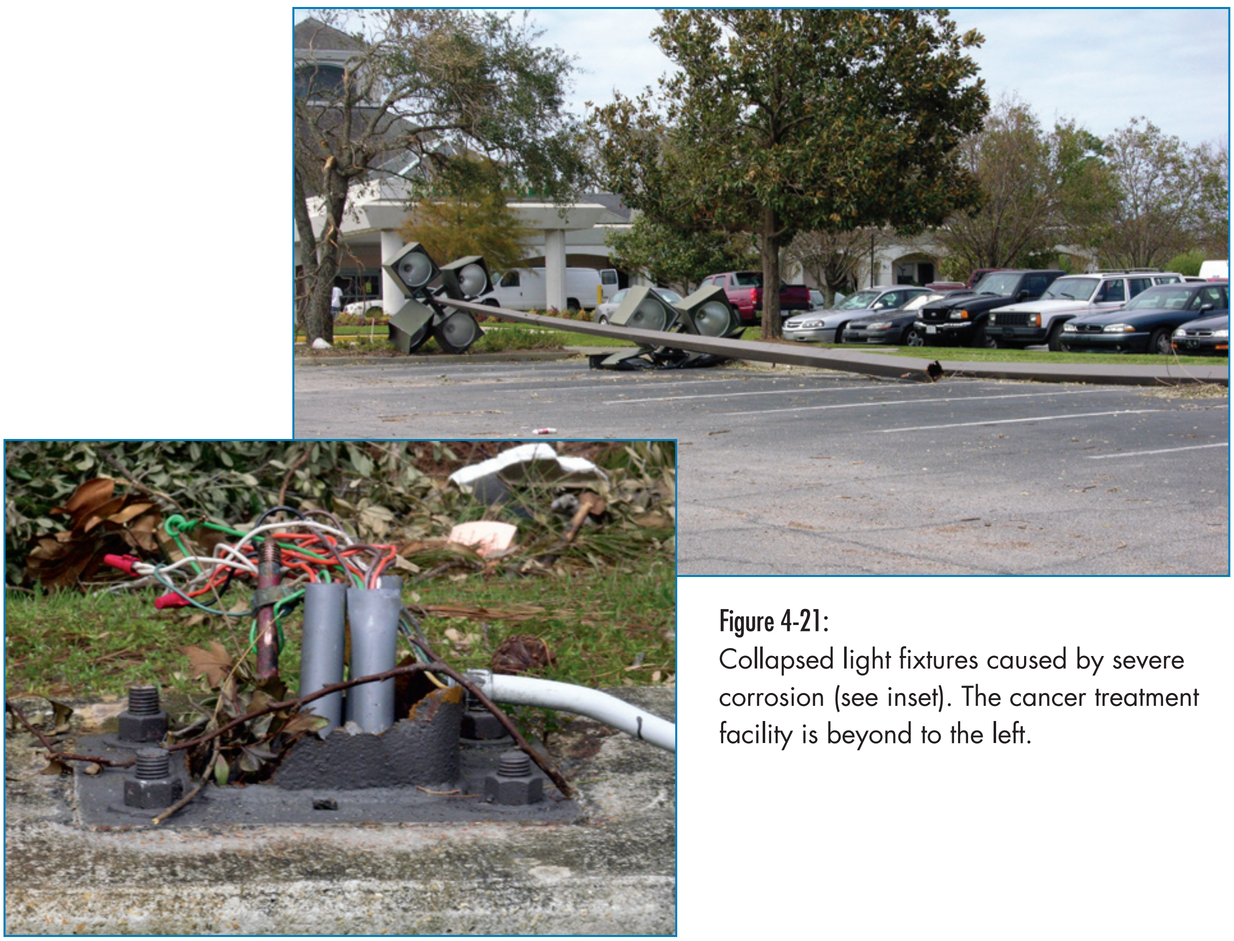


Figure 4-21:
Collapsed light fixtures caused by severe corrosion (see inset). The cancer treatment facility is beyond to the left.

Figure 4-22: The only remaining portion of the exterior wall surrounding the elevator penthouse on the MOB was the steel studs.

Figure 4-23: Close-up of the damaged EIFS at the hospital. In this area most of the insulation and gypsum board was blown from the steel furring channels.

## 4.2.2 EVALUATING HOSPITALS FOR RISK FROM HIGH WINDS

This section describes the process of hazard risk assessment. Although no formal methodology for risk assessment has been adopted, prior experience provides a sufficient knowledge base upon which a set of guidelines can be structured into a recommended procedure for risk assessment of hospitals. The procedures presented below establish guidelines for evaluating the risk to new and existing buildings from windstorms other than tornadoes. These evaluations will allow development of a vulnerability assessment that can be used along with the site's wind regime to assess the risk to hospitals.

In the case of tornadoes, neither the IBC nor ASCE 7 requires buildings (including hospitals) to be designed to resist tornado forces, nor are occupant shelters required in buildings located in tornado-prone regions. Constructing tornado-resistant hospitals is extremely expensive because of the extremely high pressures and missile impact loads that tornadoes can generate. Therefore, when consideration is voluntarily given to tornado design, the emphasis is typically on occupant protection, which is achieved by "hardening" portions of a hospital for use as safe havens. FEMA 361 includes a comprehensive risk assessment procedure that designers can use to assist building owners in determining whether a tornado shelter should be included as part of a new hospital. See Section 4.5 for recommendations pertaining to hospitals in tornado-prone regions.

### 4.2.2.1 New Buildings

When designing new hospitals, a two-step procedure is recommended for evaluating the risk from windstorms (other than tornadoes).

**Step 1:** Determine the basic wind speed from ASCE 7. As the basic wind speed increases beyond 90 mph, the risk of damage increases. Design, construction, and maintenance enhancements are recommended to compensate for the increased risk of damage (see Section 4.3).

**Step 2:** For hospitals in hurricane-prone regions, refer to the design, construction, and maintenance enhancements recommended in Sections 4.3.1.5, 4.3.2.1, 4.3.3.2, 4.3.3.4, 4.3.3.6, 4.3.3.8, 4.3.4.2, 4.3.4.4, 4.3.5, and 4.3.6.

For hospitals in remote areas outside of hurricane-prone regions, it is recommended that robust design measures be considered to minimize the potential for disruption resulting from wind damage. Because of their remote location, disruption of hospitals could severely affect patients. Some of the recommendations in the sections pertaining to hurricane-prone regions may therefore be prudent.

#### 4.2.2.2 Existing Buildings

The resistance of existing buildings is a function of their original design and construction, various additions or modifications, and the condition of building components (which may have weakened due to deterioration or fatigue). For existing buildings, a two-step procedure is also recommended.

**Step 1:** Calculate the wind loads on the building using the current edition of ASCE 7, and compare these loads with the loads for which the building was originally designed. The original design loads may be noted on the contract drawings. If not, determine what building code or standard was used to develop the original design loads, and calculate the loads using that code or standard. If the original design loads are significantly lower than current loads, upgrading the load resistance of the building envelope and/or structure should be considered. An alternative to comparing current loads with original design loads is to evaluate the resistance of the existing facility as a function of the current loads to determine what elements are highly overstressed.

**Step 2:** Perform a field investigation to evaluate the primary building envelope elements, rooftop equipment, and structural system elements, to determine if the facility was generally constructed as indicated on the original contract drawings. As part of the investigation, the primary elements should be checked for deterioration. Load path continuity should also be checked.

If the results of either step indicate the need for remedial work, see Section 4.4.

# 4.3 REQUIREMENTS AND BEST PRACTICES IN HIGH-WIND REGIONS

## 4.3.1 GENERAL HOSPITAL DESIGN CONSIDERATIONS

The performance of hospitals in past wind storms indicates that the most frequent and the most significant factor in the disruption of the operations of these facilities has been the failure of nonstructural building components. While acknowledging the importance of the structural systems, Chapter 4 emphasizes the building envelope components and the nonstructural systems. According to National Institute of Building Sciences (NIBS), the building envelope includes the below-grade basement walls and foundation and floor slab (although these are generally considered part of the building's structural system). The envelope includes everything that separates the interior of a building from the outdoor environment, including the connection of all the nonstructural elements to the building structure. The nonstructural systems include all mechanical, electrical, electronic, communications, and lightning protection systems. Historically, damage to roof coverings and rooftop equipment has been the leading cause of building performance problems during windstorms. Special consideration should be given to the problem of water infiltration through failed building envelope components, which can cause severe disruptions in the functioning of hospitals.

The key to enhanced wind performance is paying sufficient attention to all phases of the construction process (including site selection, design, and construction) and to post-occupancy maintenance and repair.

### Hospital Design Considerations In Hurricane-Prone Regions

Following the general design and construction recommendations, this manual presents recommendations specific to hospitals located in hurricane-prone regions. These recommendations are additional to the ones presented for hospitals located outside of hurricane-prone regions, and in many cases supersede those recommendations. Hospitals located in hurricane-prone regions require special design and construction attention because of the unique characteristics of this type of windstorm. Hurricanes can bring very high winds that last for many hours, which can lead to material fatigue failures. The variability of wind direction increases the probability that the wind will approach the building at the most critical angle. Hurricanes also generate a large amount of wind-borne debris, which can damage various building components and cause injury and death.

Hospitals in hurricane-prone regions require special attention because they normally have vulnerable occupants (patients) at the time of a hurricane, and afterwards, many injured people seek medical care. Significant damage to a hospital can put patients at risk and jeopardize delivery of care to those seeking treatment. In order to ensure continuity of service during and after hurricanes, the design, construction, and maintenance of hospitals should be very robust to provide sufficient resiliency to withstand the effects of hurricanes.

Because of advanced warning of impending land fall, with the exception of Hurricane Katrina (Louisiana and Mississippi, 2005), the death toll from hurricanes in the U.S. has been extremely low for the last several decades. However, large numbers of people are often injured and seek care at hospitals. Blunt-force trauma injuries caused by wind-borne debris, falling trees, collapsed ceilings, or partial building collapse occur during hurricanes. But most of the hurricane-related injuries typically occur in the days afterward. These injuries are typically due to chainsaw accidents, stepping on nails, lacerations incurred while removing debris, vehicle accidents at intersections that no longer have functional traffic lights, people falling off roofs as they attempt to make emergency repairs, and carbon monoxide poisoning or electrical shock from improper use of emergency generators. Therefore, at a time when many hospitals in an area may be functionally impaired or no longer capable of providing service due to building damage (Figures 4-1 and 4-8), hospital staffs are faced with a higher than normal number of people seeking treatment. Before arrival of a hurricane, hospitals also often receive an influx of women in their third trimester of pregnancy, so that they will already be at the hospital in case they go into labor during the storm or shortly thereafter, when getting to the hospital could be hazardous or impossible.

Full or partial evacuation of a hospital prior to, during, or after a hurricane is time consuming, expensive, and for some patients, potentially life threatening. Water infiltration that could damage electrical equipment or medical supplies, or inhibit the use of critical areas (such as operating rooms and nursing floors) needs to be prevented. The emergency and standby power systems need to remain operational and be adequately sized to power all needed circuits, including the HVAC system. Provisions are needed for water and sewer service in the event of loss of municipal services, and antenna towers need to be strong enough to resist the wind.

#### 4.3.1.1 Site

When selecting land for a hospital, sites located in Exposure D (see ASCE 7 for exposure definitions) should be avoided if possible. Selecting a site in Exposure C or preferably in Exposure B would decrease the wind loads. Also, where possible, avoid selecting sites located on an escarpment or the upper half of a hill, where the abrupt change in the topography would result in increased wind loads.[7]

Trees with trunks larger than 6 inches in diameter, poles (e.g., light fixture poles, flagpoles, and power poles), or towers (e.g., electrical transmission and large communication towers) should not be placed near the building. Falling trees, poles, and towers can severely damage a hospital and injure the occupants (see Figure 4-24). Large trees can crash through pre-engineered metal buildings and wood frame construction. Falling trees can also rupture roof membranes and break windows.


**Figure 4-24:** The roof membrane on this hospital's materials management facility was ruptured by falling trees. Hurricane Ivan (Florida, 2004)

Street signage should be designed to resist the design wind loads so that toppled signs do not block access roads or become wind-blown debris. AASHTO LTS-4-M (amended by LTS-4-12 2001 and 2003, respectively) provides guidance for determining wind loads on highway signs.

Providing at least two means of site egress is prudent for all hospitals, but is particularly important for hospitals in hurricane-prone regions. If one route becomes blocked by trees or other debris, or by floodwaters, the other access route may still be available.

7 When selecting a site on an escarpment or the upper half of a hill is necessary, the ASCE 7 design procedure accounts for wind speed-up associated with this abrupt change in topography.

### 4.3.1.2 Building Design

Good wind performance depends on good design (including details and specifications), materials, installation, maintenance, and repair. A significant shortcoming in any of these five elements could jeopardize the performance of a hospital against wind. Design, however, is the key element to achieving good performance of a building against wind damage. Design inadequacies frequently cannot be compensated for with other elements. Good design, however, can compensate for other inadequacies to some extent. The following steps should be included in the design process for hospitals.

#### Step 1: Calculate Loads

Calculate loads on the MWFRS, the building envelope, and rooftop equipment in accordance with ASCE 7 or the local building code, whichever procedure results in the highest loads. In calculating wind loads, design professionals should consider the following items.

> In the past, design professionals seldom performed load calculations on the building envelope (i.e., roof and wall coverings, doors, windows, and skylights) and rooftop equipment. These building components are the ones that have failed the most during past wind events. In large part they failed because of the lack of proper load determination and inappropriate design of these elements. It is imperative that design professionals determine the loads for the building envelope and rooftop equipment, and design them to accommodate such loads.

**Importance factor:** The effect of using a 1.15 importance factor versus 1 is that the design loads for the MWFRS and C&C are increased by 15 percent. The importance factor for hospitals is required to be 1.15. However, some buildings on a hospital campus, such as medical office buildings that are integrally connected to the hospital and various types of non-emergency treatment facilities (such as storage, cancer treatment, physical therapy, and dialysis), are not specifically required by ASCE 7 to be designed with a 1.15 factor. This manual recommends a value of 1.15 for all facilities on a hospital campus.

**Wind directionality factor:** The ASCE 7 wind load calculation procedure incorporates a wind directionality factor ($k_d$). The directionality factor accounts for the reduced probability of maximum winds coming from any given direction. By applying the prescribed value of 0.85, the loads are reduced by 15 percent. Because hurricane winds can come from any direction, and because of the historically poor performance of building envelopes and rooftop equipment, this manual recommends a more conservative approach for

> Uplift loads on roof assemblies can also be determined from FM Global (FMG) Data Sheets. If the hospital is FMG insured, and the FMG-derived loads are higher than those derived from ASCE 7 or the building code, the FMG loads should govern. However, if the ASCE 7 or code-derived loads are higher than those from FMG, the ASCE 7 or code-derived loads should govern (whichever procedure results in the highest loads).

hospitals in hurricane-prone regions. A directionality factor of 1.0 is recommended for the building envelope and rooftop equipment (a load increase over what is required by ASCE 7). For the MWFRS, a directionality factor of 0.85 is recommended (hence, no change for MWFRS).

### Step 2: Determine Load Resistance

When using allowable stress design, after loads have been determined, it is necessary to determine a reasonable safety factor in order to select the minimum required load resistance. For building envelope systems, a minimum safety factor of 2 is recommended. For anchoring exterior-mounted mechanical, electrical, and communications equipment (such as satellite dishes), a minimum safety factor of 3 is recommended. When using strength design, load combinations and load factors specified in ASCE 7 are used.

> When using allowable stress design, a safety factor is applied to account for reasonable variations in material strengths, construction workmanship, and conditions when the actual wind speed somewhat exceeds the design wind speed. For design purposes, the ultimate resistance an assembly achieves in testing is reduced by the safety factor. For example, if a roof assembly resisted an uplift pressure of 100 pounds per square foot (psf), after applying a safety factor of 2, the assembly would be suitable where the design load was 50 psf or less. Conversely, if the design load is known, multiplying it by the safety factor equals the minimum required test pressure (e.g., 50 psf design load multiplied by a safety factor of 2 equals a minimum required test pressure of 100 psf).

ASCE 7 provides criteria for combining wind loads with other types of loads (such as dead and flood loads) using allowable stress design.

For structural members and cladding elements where strength design can be used, load resistance can be determined by calculations. For other elements where allowable stress design is used (such as most types of roof coverings), load resistance is primarily obtained from system testing.

The load resistance criteria need to be provided in contract documents. For structural elements, the designer of record typically accounts for load resistance by indicating the material, size, spacing, and connection of the elements. For nonstructural elements, such as roof coverings or windows, the load and safety factor can be specified. In this case, the specifications should require the contractor's submittals to demonstrate that the system will meet the load resistance criteria. This performance specification approach is necessary if, at the time of the design, it is unknown who will manufacture the system.

Regardless of which approach is used, it is important that the designer of record ensure that it can be demonstrated, via calculations or tests, that the structure, building envelope, and nonstructural systems (exterior-mounted mechanical, electrical, and communications equipment) have sufficient strength to resist design wind loads.

### Step 3: Detailed Design

It is vital to design, detail, and specify the structural system, building envelope, and exterior-mounted mechanical, electrical, and communications equipment to meet the factored design loads (based on appropriate analytical or test methods). It is also vital to respond to the risk assessment criteria discussed in Section 4.2.2, as appropriate.

> Connections are a key aspect of load path continuity between various structural and nonstructural building elements. In a window, for example, the glass must be strong enough to resist the wind pressure and must be adequately anchored to the window frame, the frame adequately anchored to the wall, the wall to the foundation, and the foundation to the ground. As loads increase, greater load capacity must be developed in the connections.

As part of the detailed design effort, load path continuity should be clearly indicated in the contract documents via illustration of connection details. Load paths need to accommodate design uplift, racking, and overturning loads. Load path continuity obviously applies to MWFRS elements, but it also applies to building envelope elements. Figure 4-25 shows a load path discontinuity between a piece of HVAC equipment and its equipment stand. The equipment on this new building blew away because it was resting on vibration isolators that provided lateral resistance, but no uplift resistance (also see Figure 4-92).

**Figure 4-25:**
Temporary coverings placed over two large openings in the roof that were left after the ductwork blew away. Hurricane Katrina (Mississippi, 2005)

Figure 4-26 illustrates the load path concept. Members are sized to accommodate the design loads. Connections are designed to transfer uplift loads applied to the roof, and the positive and negative loads applied to the exterior bearing walls, down to the foundation and into the ground. The roof covering (and wall covering, if there is one) is also part of the load path. To avoid blow-off, the nonstructural elements must also be adequately attached to the structure.

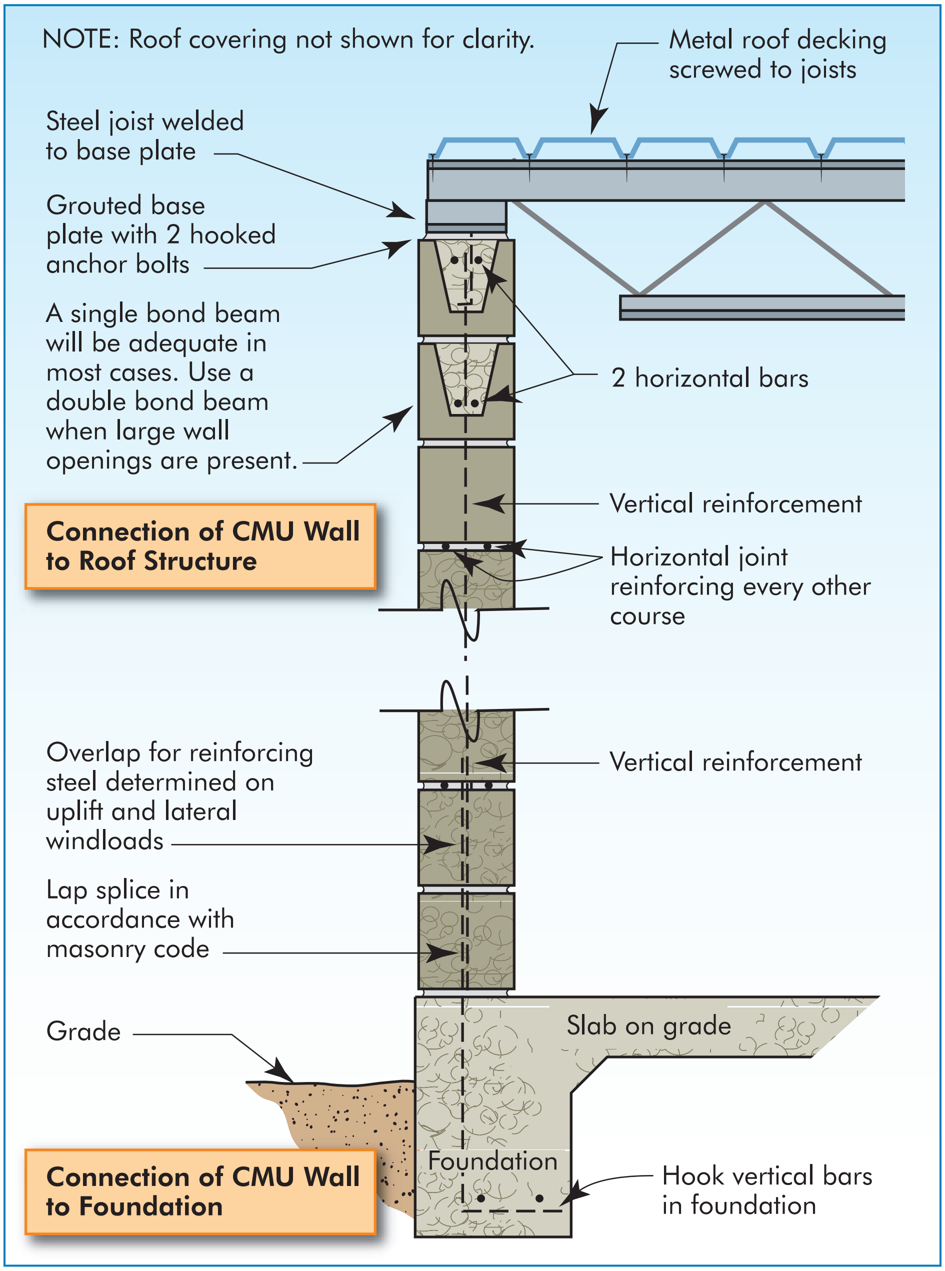



**Figure 4-26:** Illustration of load path continuity

As part of the detailed design process, special consideration should be given to the durability of materials and water infiltration.

**Durability:** Because some locales have very aggressive atmospheric corrosion (such as areas near oceans), special attention needs to be given to the specification of adequate protection for ferrous metals, or to specify alternative metals such as stainless steel. FEMA Technical Bulletin, *Corrosion Protection for Metal Connectors in Coastal Areas* (FIA-TB-8, 1996), contains information on corrosion protection. Attention also needs to be given to dry rot avoidance, for example, by specifying preservative-treated wood or developing details that avoid excessive moisture accumulation. Appendix J of the *Coastal Construction Manual,* (FEMA 55, 2000) presents information on wood durability.

Further information on the rain-screen principle can be found in the National Institute of Building Sciences' Building Envelope Design Guide (www.wbdg.org/design/envelope.php).

Durable materials are particularly important for components that are inaccessible and cannot be inspected regularly (such as fasteners used to attach roof insulation). Special attention also needs to be given to details. For example, details that do not allow water to stand at connections or sills are preferred. Without special attention to material selection and details, the demands on maintenance and repair will be increased, along with the likelihood of failure of components during high winds.

**Water infiltration (rain):** Although prevention of building collapse and major building damage is the primary goal of wind-resistant design, consideration should also be given to minimizing water damage and subsequent development of mold from the penetration of wind-driven rain. To the extent possible, non-load-bearing walls and door and window frames should be designed in accordance with rain-screen principles. With this approach, it is assumed that some water will penetrate past the face of the building envelope. The water is intercepted in an air-pressure equalized cavity that provides drainage from the cavity to the outer surface of the building. See Sections 4.3.3.1 and 4.3.3.5, and Figure 4-45 for further discussion and an example.

Coastal environments are conducive to metal corrosion, especially in buildings within 3,000 feet of the ocean. Most jurisdictions require metal building hardware to be hot-dipped galvanized or stainless steel. Some local codes require protective coatings that are thicker than typical "off-the-shelf" products. For example, a G90 zinc coating (0.75 mil on each face) may be required. Other recommendations include the following:

- Use hot-dipped galvanized or stainless steel hardware. Reinforcing steel should be fully protected from corrosion by the surrounding material (masonry, mortar, grout, or concrete). Use galvanized or epoxy-coated reinforcing steel in situations where the potential for corrosion is high.
- Avoid joining dissimilar metals, especially those with high galvanic potential.
- Avoid using certain wood preservatives in direct contact with galvanized metal. Verify that wood treatment is suitable for use with galvanized metal, or use stainless steel.
- Metal-plate-connected trusses should not be exposed to the elements. Truss joints near vent openings are more susceptible to corrosion and may require increased corrosion protection.

**Note:** *Although more resistant than other metals, stainless steel is still subject to corrosion.*

In conjunction with the rain-screen principle, it is desirable to avoid using sealant as the first or only line of defense against water infiltration. When sealant joints are exposed, obtaining long-lasting watertight performance is difficult because of the complexities of sealant joint design and installation (see Figure 4-45, which shows the sealant protected by a removable stop).

#### Step 4: Peer Review

If the design team's wind expertise and experience is limited, wind design input and/or peer review should be sought from a qualified individual. The design input or peer review could be arranged for the entire building, or for specific components, such as the roof or glazing systems, that are critical and beyond the design team's expertise.

Regardless of the design team's expertise and experience, peer review should be considered when a hospital:

- Is located in an area where the basic wind speed is greater than 90 mph (peak gust).
- Will incorporate a tornado shelter.

### 4.3.1.3 Construction Contract Administration

After a suitable design is complete, the design team should endeavor to ensure that the design intent is achieved during construction. The key elements of construction contract administration are submittal reviews and field observations, as discussed below.

**Submittal reviews:** The specifications need to stipulate the submittal requirements. This includes specifying what systems require submittals (e.g., windows) and test data (where appropriate). Each submittal should demonstrate the development of a load path through the system and into its supporting element. For example, a window submittal should show that the glazing has sufficient strength, its attachment to the frame is adequate, and the attachment of the frame to the wall is adequate.

During submittal review, it is important for the designer of record to be diligent in ensuring that all required documents are submitted and that they include the necessary information. The submittal information needs to be thoroughly checked to ensure its validity. For example, if an approved method used to demonstrate compliance with the design load has been altered or incorrectly applied, the test data should be rejected, unless the contractor can demonstrate the test method was suitable.

Similarly, if a new test method has been developed by a manufacturer or the contractor, the contractor should demonstrate its suitability.

**Field observations:** It is recommended that the design team analyze the design to determine which elements are critical to ensuring high-wind performance. The analysis should include the structural system and exterior-mounted electrical equipment, but it should focus on the building envelope and exterior-mounted mechanical and communications equipment. After determining the list of critical elements to be observed, observation frequency and the need for special inspections by an inspection firm should be determined. Observation frequency and the need for special inspections will depend on the magnitude of the results of the risk assessment described in Section 4.2.2, complexity of the facility, and the competency of the general contractor, subcontractors, and suppliers.

#### 4.3.1.4 Post-Occupancy Inspections, Periodic Maintenance, Repair, and Replacement

The design team should advise the building owner of the importance of periodic inspections, maintenance, and timely repair. It is important for the building owner to understand that a facility's wind resistance will degrade over time due to exposure to weather unless it is regularly maintained and repaired. The goal should be to repair or replace items before they fail in a storm. This approach is less expensive than waiting for failure and then repairing the failed components and consequential damage.

The building envelope and exterior-mounted equipment should be inspected once a year by persons knowledgeable of the systems/materials they are inspecting. Items that require maintenance, repair, or replacement should be documented and scheduled for work. For example, the deterioration of glazing is often overlooked. After several years of exposure, scratches and chips can become extensive enough to weaken the glazing. Also, if an engineered film was surface-applied to glazing for wind-borne debris protection, the film should be periodically inspected and replaced before it is no longer effective.

A special inspection is recommended following unusually high winds (such as a thunderstorm with wind speeds of 70 mph peak gust or greater). The purpose of the inspection is to assess whether the storm caused damage that needs to be repaired to maintain building strength and integrity. In addition to inspecting for obvious signs of damage, the inspector should determine if cracks or other openings have developed that may allow water infiltration, which could lead to corrosion or dry rot of concealed components.

#### 4.3.1.5 Site and General Design Considerations in Hurricane-Prone Regions

Via ASCE 7, the 2006 edition of the IBC has only one special wind-related provision pertaining to hospitals in hurricane-prone regions. It pertains to glazing protection within wind-borne debris regions (as defined in ASCE 7). This single additional requirement does not provide adequate protection for occupants of a hospital during a hurricane, nor does it ensure a hospital will remain functional during and after a hurricane. A hospital may comply with IBC but still remain vulnerable to water and missile penetration through the roof or walls. To provide occupant protection, the exterior walls and the roof must be designed and constructed to resist wind-borne debris as discussed in Sections 4.3.2.1, 4.3.3.2, 4.3.3.4, 4.3.3.6, and 4.3.3.8. The following recommendations are made regarding siting:

- Locate poles, towers, and trees with trunks larger than 6 inches in diameter away from primary site access roads so that they do not block access to, or hit, the facility if toppled.

- Determine if existing buildings within 1,500 feet of the new facility have aggregate surfaced roofs. If roofs with aggregate surfacing are present, it is recommended that the aggregate be removed to prevent it from striking the new facility. Aggregate removal may necessitate reroofing or other remedial work in order to maintain the roof's fire or wind resistance.

- In cases where multiple buildings are occupied during a storm, it is recommended that enclosed walkways be designed to connect the buildings. The enclosed walkways (above- or below-grade) are particularly important for protecting people moving between buildings during a hurricane (e.g., to retrieve equipment or supplies) or for situations when it is necessary to evacuate occupants from one building to another during a hurricane (see Figure 4-27).

Figure 4-27: Open walkways do not provide protection from wind-borne debris. (Hurricane Katrina, Mississippi)

### 4.3.2 STRUCTURAL SYSTEMS

Based on post-storm damage evaluations, with the exception of strong and violent tornado events, the structural systems (i.e., MWFRS and structural components such as roof decking) of hospitals have typically performed quite well during design wind events. There have, however, been notable exceptions; in these cases, the most common problem has been blow-off of the roof deck, but instances of collapse have also been documented (Figure 4-34). The structural problems have primarily been caused by lack of an adequate load path, with connection failure being a common occurrence. Problems have also been caused by workmanship errors (commonly associated with steel decks attached by puddle welds), and limited uplift resistance of deck connections in roof perimeters and corners (due to lack of code-required enhancement in older editions of the model codes).

With the exception of strong and violent tornado events, structural systems designed and constructed in accordance with the IBC should typically offer adequate wind resistance, provided attention was given to load path continuity and to the durability of building materials (with respect to corrosion and termites). However, the greatest reliability is offered by cast-in-place concrete. There are no known reports of any cast-in-place concrete buildings experiencing a significant structural problem during wind events, including the strongest hurricanes (Category 5) and tornadoes (F5).

The following design parameters are recommended for structural systems:

- If a pre-engineered metal building is being contemplated, special steps should be taken to ensure the structure has more redundancy than is typically the case with pre-engineered buildings.[8] Steps should be taken to ensure the structure is not vulnerable to progressive collapse in the event a primary bent (steel moment frame) is compromised or bracing components fail.

- Exterior load-bearing walls of masonry or precast concrete should be designed to have sufficient strength to resist external and internal loading when analyzed as C&C. CMU walls should have vertical and horizontal reinforcing and grout to resist wind loads. The connections of precast concrete wall panels should be designed to have sufficient strength to resist wind loads.

- For roof decks, concrete, steel, plywood, or oriented strand board (OSB) is recommended.

- For steel roof decks, it is recommended that a screw attachment be specified, rather than puddle welds or powder-driven pins. Screws are more reliable and much less susceptible to workmanship problems. Figure 4-28 shows decking that was attached with puddle welds. At most of the welds, there was only superficial bonding of the metal deck to the joist, as illustrated by this example. Only a small portion of the deck near the center of the weld area (as delineated by the circle) was well fused to the joist. Figures 4-29 and 4-30 show problems with acoustical decking attached with powder-driven pins. The pin shown on the left of Figure 4-30 is properly seated. However, the pin at the right did not penetrate far enough into the steel joist below.

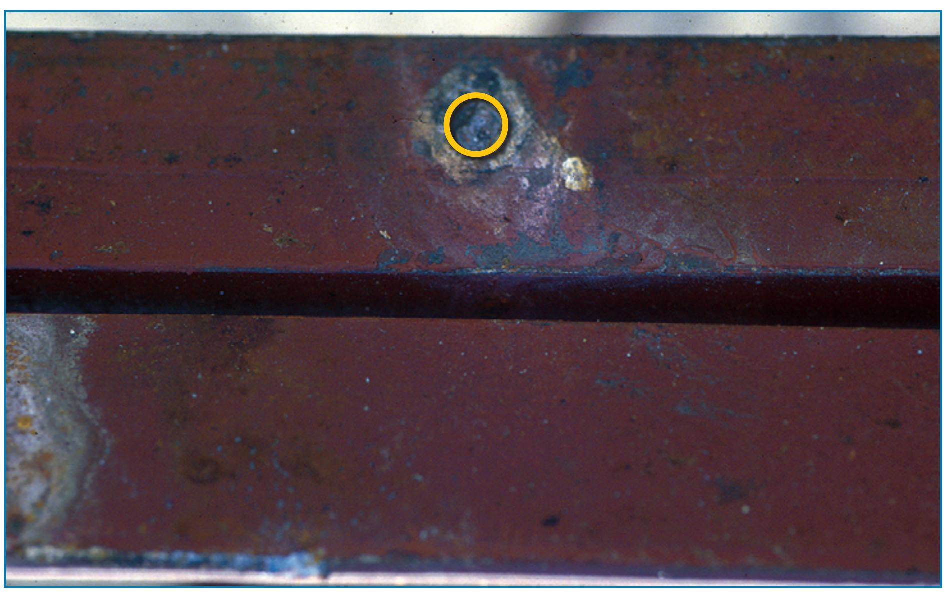


**Figure 4-28:**
View looking down at the top of a steel joist after the metal decking blew away. Only a small portion of the deck was well fused to the joist (circled area). Tornado (Oklahoma, 1999)

8 The structural system of pre -engineered metal buildings is composed of rigid steel frames, secondary members (including roof purlins and wall girts made of Z- or C-shaped members) and bracing.

Figure 4-29:
Looking down at a sidelap of a deck attached with powder-driven pins. The washer at the top pin blew through the deck.

Figure 4-30:
View looking along a sidelap of a deck attached with powder-driven pins. The right pin does not provide adequate uplift and shear resistance.

- For attaching wood-sheathed roof decks, screws, ring-shank, or screw-shank nails are recommended in the corner regions of the roof. Where the basic wind speed is greater than 90 mph, these types of fasteners are also recommended for the perimeter regions of the roof.

- For precast concrete decks it is recommended that the deck connections be designed to resist the design uplift loads because the deck dead load itself is often insufficient to resist the uplift. The deck in Figure 4-31 had bolts to provide uplift resistance; however, anchor plates and nuts had not been installed. Without the anchor plates, the dead load of the deck was insufficient to resist the wind uplift load.

Figure 4-31:
Portions of this waffled precast concrete roof deck were blown off. Typhoon Paka (Guam, 1997)

- For precast Tee decks, it is recommended that the reinforcing be designed to accommodate the uplift loads in addition to the gravity loads. Otherwise, large uplift forces can cause member failure due to the Tee's own pre-stress forces after the uplift load exceeds the dead load of the Tee. This type of failure occurred at one of the roof panels shown in Figure 4-32, where a panel lifted because of the combined effects of wind uplift and pre-tension. Also, because the connections between the roof and wall panels provided very little uplift load resistance, several other roof and wall panels collapsed.

**Figure 4-32:** Twin-Tee roof panel lifted as a result of the combined effects of wind uplift and pre-tension. Tornado (Missouri, May 2003)

- For buildings that have mechanically attached single-ply or modified bitumen membranes, designers should refer to the decking recommendations presented in the *Wind Design Guide for Mechanically Attached Flexible Membrane Roofs*, B1049 (National Research Council of Canada, 2005).

> ASCE 7-05 provides pressure coefficients for open canopies of various slopes (referred to as "free roofs" in ASCE 7). The free roof figures for MWFRS in ASCE 7-05 (Figures 6-18A to 6-18D) include two load cases, Case A and Case B. While there is no discussion describing the two load cases, they pertain to fluctuating loads and are intended to represent upper and lower limits of instantaneous wind pressures. Loads for both cases must be calculated to determine the critical loads. Figures 6-18A to 6-18C are for a wind direction normal to the ridge. For wind direction parallel to the ridge, use Figure 6-18D in ASCE 7-05.

- If an FMG-rated roof assembly is specified, the roof deck also needs to comply with the FMG criteria.

- Walkway and entrance canopies are often damaged during high winds (see Figure 4-33). Wind-borne debris from damaged canopies can damage nearby buildings and injure people, hence these elements should also receive design and construction attention.

**Figure 4-33:** The destroyed walkway canopy in front of this building became wind-borne debris. Hurricane Ivan (Florida, 2004)

### 4.3.2.1 Structural Systems in Hurricane-Prone Regions

Because of the exceptionally good wind performance and wind-borne debris resistance that reinforced cast-in-place concrete structures offer, a reinforced concrete roof deck and reinforced concrete or reinforced and fully grouted CMU exterior walls are recommended as follows:

**Roof deck:** A minimum 4-inch-thick, cast-in-place reinforced concrete deck is the preferred deck. Other recommended decks are minimum 4-inch-thick structural concrete topping over steel decking, and precast concrete with an additional minimum 4-inch structural concrete topping.

> If precast concrete is used for the roof or wall structure, the connections should be carefully designed, detailed, and constructed.

If these recommendations are not followed for hospitals located in areas where the basic wind speed is 100 mph or greater, it is recommended that the roof assembly be able to resist complete penetration of the deck by the “D” missile specified in ASTM E 1996 (2005) (see text box in Section 4.3.3.2).

**Exterior load-bearing walls:** A minimum 6-inch-thick, cast-in-place concrete wall reinforced with #4 rebars at 12 inches on center each way is the preferred wall. Other recommended walls are a minimum 8-inch-thick fully grouted CMU reinforced vertically with #4 rebars at 16 inches on center, and precast concrete that is a minimum 6-inches-thick and reinforced equivalent to the recommendations for cast-in-place walls.

### 4.3.3 BUILDING ENVELOPE

The following section highlights the design considerations for building envelope components that have historically sustained the greatest and most frequent damage in high winds.

The design considerations for building envelope components of hospitals in hurricane-prone regions include a number of additional recommendations. The principal concern that must be addressed is the additional risk from wind-borne debris and water leakage. Design considerations specific to hurricane-prone regions are discussed in Sections 4.3.3.2, 4.3.3.4, 4.3.3.6, and 4.3.3.8.

#### 4.3.3.1 Exterior Doors

This section addresses primary and secondary egress doors, sectional (garage) doors, and rolling doors. Although blow-off of personnel doors is uncommon, it can cause serious problems (see Figure 4-34). Blown-off doors allow entrance of rain, and tumbling doors can damage buildings and cause injuries.

> For further general information on doors, see "Fenestration Systems" in the National Institute of Building Sciences' Building Envelope Design Guide (www.wbdg.org/design/envelope.php).

Blown off sectional and rolling doors are quite common. These failures are typically caused by the use of door and track assemblies that have insufficient wind resistance, or by inadequate attachment of the tracks or nailers to the wall (see Figure 4-35).

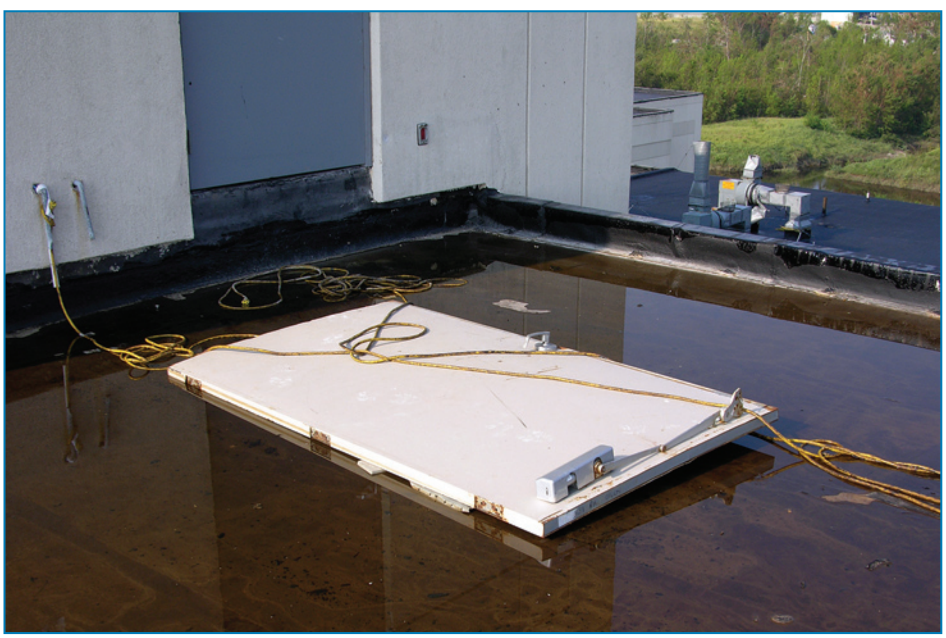


**Figure 4-34:** Door on a hospital penthouse blown off its hinges during Hurricane Katrina (Mississippi, 2005)

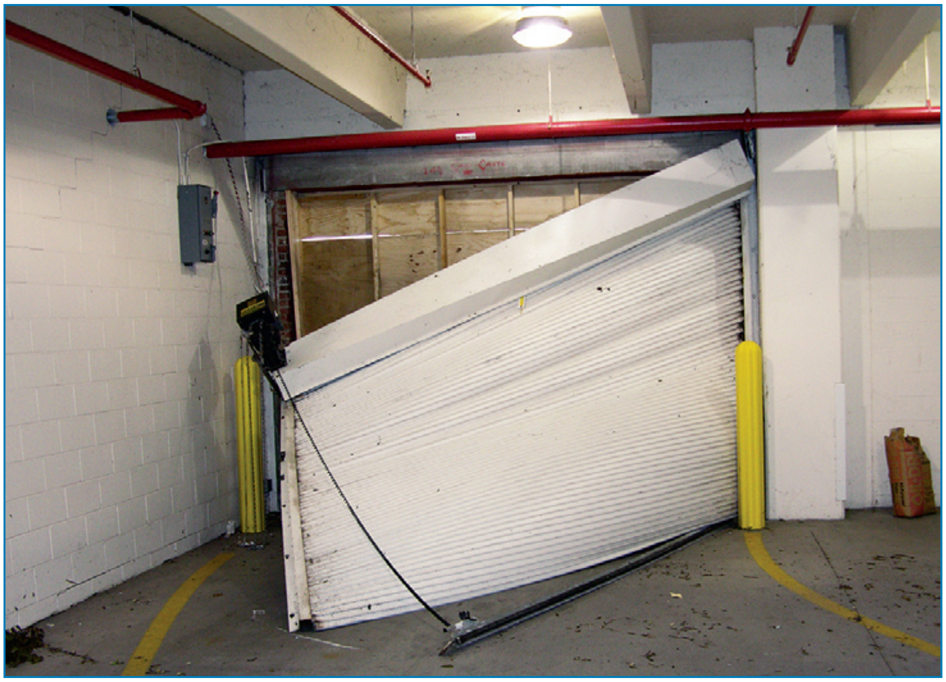


**Figure 4-35:**
This new rolling door failed because the CMU spalled at the door frame's expansion bolts, which were too close to the end of the CMU. Hurricane Charley (Florida, 2004)

## Loads and Resistance

> For design guidance on attachment of door frames, see Technical Data Sheet #161, *Connecting Garage Door Jambs to Building Framing*, published by the Door & Access Systems Manufacturers Association, 2003 (available at www.dasma.com).

The IBC requires that the door assembly (i.e., door, hardware, frame, and frame attachment to the wall) be of sufficient strength to resist the positive and negative design wind pressure. Design professionals should require that doors comply with wind load testing in accordance with ASTM E 1233. Design professionals should also specify the attachment of the door frame to the wall (e.g., type, size, spacing, and edge distance of frame fasteners). For sectional and rolling doors attached to wood nailers, design professionals should also specify the attachment of the nailer to the wall.

## Water Infiltration

Heavy rain that accompanies high winds (e.g., thunderstorms, tropical storms, and hurricanes) can cause significant wind-driven water infiltration problems. The magnitude of the problem increases with the wind speed. Leakage can occur between the door and its frame, the frame and the wall, and between the threshold and the door. When wind speeds approach 120 mph, some leakage should be anticipated because of the very high wind pressures and numerous opportunities for leakage path development.

> Where corrosion is problematic, anodized aluminum or galvanized doors and frames, and stainless steel frame anchors and hardware are recommended.

The following recommendations should be considered to minimize infiltration around exterior doors.

**Vestibule:** Adding a vestibule allows both the inner and outer doors to be equipped with weatherstripping. The vestibule can be designed with water-resistant finishes (e.g., concrete or tile) and the floor can be equipped with a drain. In addition, installing exterior threshold trench drains can be helpful (openings must be small enough to avoid trapping high-heeled shoes). Note that trench drains do not eliminate the problem, since water can still penetrate at door edges.

For primary swinging entry/exit doors, exit door hardware is recommended to minimize the possibility of the doors being pulled open by wind suction. Exit hardware with top and bottom rods is more secure than exit hardware that latches at the jamb.

**Door swing:** Out-swinging doors have weatherstripping on the interior side of the door, where it is less susceptible to degradation, which is an advantage when compared to in-swinging doors. Some interlocking weatherstripping assemblies are available for out-swinging doors.

The successful integration of the door frame and the wall is a special challenge when designing doors. See Section 4.3.3.3 for discussion of this juncture.

ASTM E 2112 provides information pertaining to the installation of doors, including the use of sill pan flashings with end dams and rear legs (see Figure 4-36). It is recommended that designers use ASTM E 2112 as a design resource.

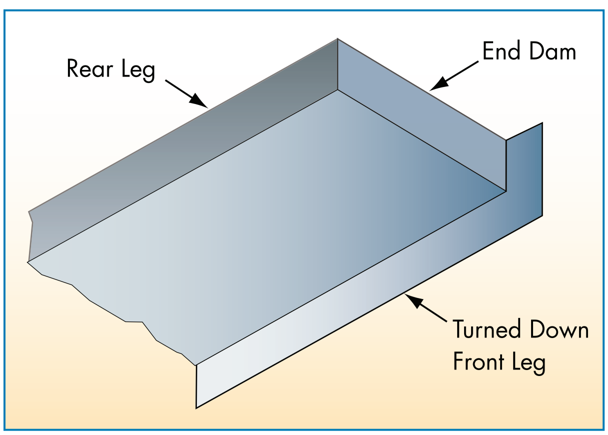



**Figure 4-36:** Door sill pan flashing with end dams, rear leg, and turned-down front leg

## Weatherstripping

A variety of pre-manufactured weatherstripping components is available, including drips, door shoes and bottoms, thresholds, and jamb/head weatherstripping.

**Drips:** These are intended to shed water away from the opening between the frame and the door head, and the opening between the door bottom and the threshold (see Figures 4-37 and 4-38). Alternatively, a door sweep can be specified (see Figure 4-38). For high-traffic doors, periodic replacement of the neoprene components will be necessary.

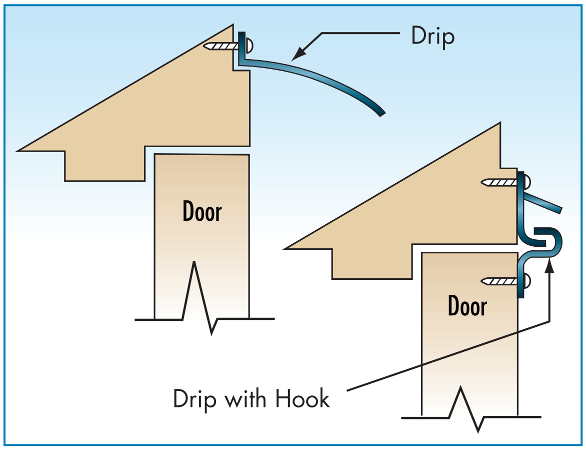



Figure 4-37:
Drip at door head and drip with hook at head

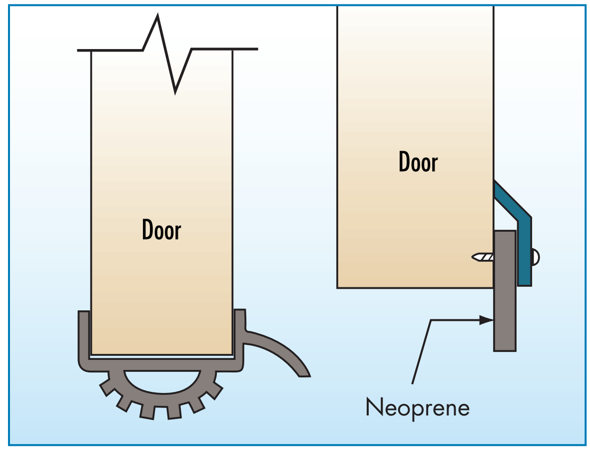



Figure 4-38:
Door shoe with drip and vinyl seal (left). Neoprene door bottom sweep (right)

**Door shoes and bottoms:** These are intended to minimize the gap between the door and the threshold. Figure 4-38 illustrates a door shoe that incorporates a drip. Figure 4-39 illustrates an automatic door bottom. Door bottoms can be surface-mounted or mortised. For high-traffic doors, periodic replacement of the neoprene components will be necessary.

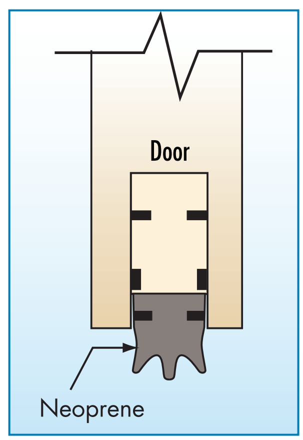



Figure 4-39:
Automatic door bottom

**Thresholds:** These are available to suit a variety of conditions. Thresholds with high (e.g., 1-inch) vertical offsets offer enhanced resistance to wind-driven water infiltration. However, the offset is limited where the thresholds are required to comply with the Americans with Disabilities Act (ADA), or at high-traffic doors. At other doors, high offsets are preferred.

Thresholds can be interlocked with the door (see Figure 4-40), or thresholds can have a stop and seal (see Figure 4-41). In some instances, the threshold is set directly on the floor. Where this is appropriate, setting the threshold in butyl sealant is recommended to avoid water infiltration between the threshold and the floor. In other instances, the threshold is set on a pan flashing (as previously discussed in this section). If the threshold has weep holes, specify that the weep holes not be obstructed during construction (see Figure 4-40).

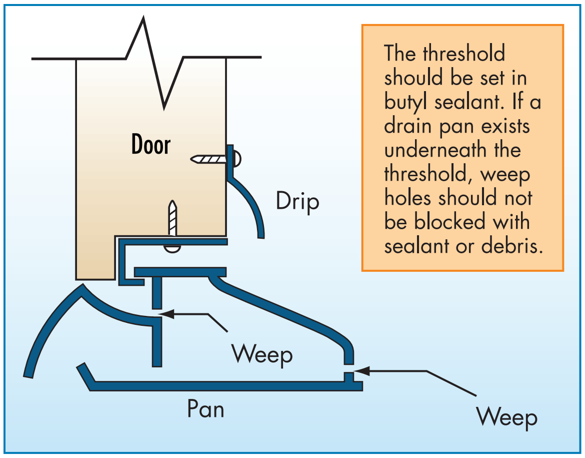



Figure 4-40: Interlocking threshold with drain pan

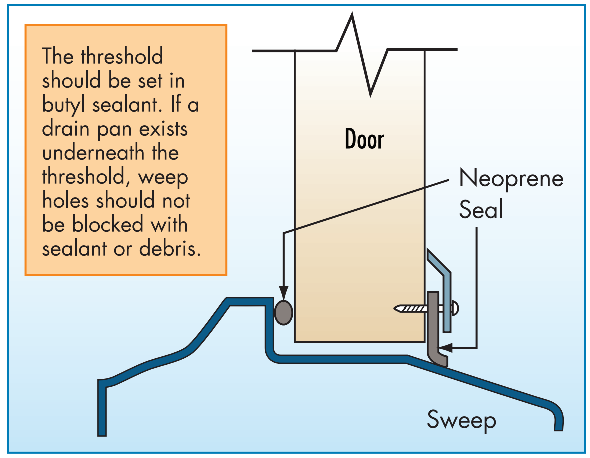
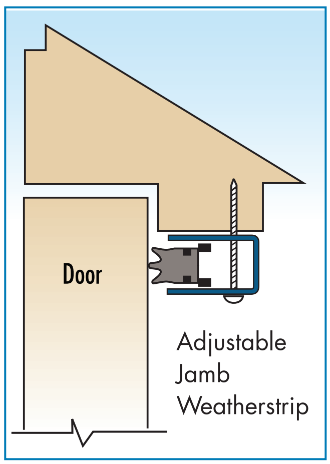



Figure 4-41: Threshold with stop and seal

Figure 4-42: Adjustable jamb/head weatherstripping




**Adjustable jamb/head weatherstripping:** This type of weatherstripping is recommended because the wide sponge neoprene offers good contact with the door (see Figure 4-42). The adjustment feature also helps to ensure good contact, provided the proper adjustment is maintained.

**Meeting stile:** At the meeting stile of pairs of doors, an overlapping astragal weatherstripping offers greater protection than weatherstripping that does not overlap.

### 4.3.3.2 Exterior Doors in Hurricane-Prone Regions

Although the ASCE-7 wind-borne debris provisions only apply to glazing within a portion of hurricane-prone regions, it is recommended that all hospitals located where the basic wind speed is 100 mph or greater comply with the following recommendations:

❍ To minimize the potential for missiles penetrating exterior doors and striking people inside the facility, it is recommended that doors (with and without glazing) be designed to resist the "E" missile load specified in ASTM E 1996. The doors should be tested in accordance with ASTM E 1886 (2005). The test assembly should include the door, door frame, and hardware.

ASTM E 1996 specifies five missile categories, A through E. The missiles are of various weights and fired at various velocities during testing. Building type (critical or non-critical) and basic wind speed determine the missiles required for testing. Of the five missiles, the E missile has the greatest momentum. Missile E is required for critical facilities located where the basic wind speed is greater than or equal to 130 mph. Missile D is permitted where the basic wind speed is less than130 mph. FEMA 361 also specifies a missile for shelters. The shelter missile has much greater momentum than the D and E missiles, as shown below:

| Missile | Missile Weight | Impact Speed | Momentum |
|---|---|---|---|
| **ASTM E 1996—D** | 9 pound 2x4 lumber | 50 feet per second (34 mph) | 14 $lb_f$ -s* |
| **ASTM E 1996—E** | 9 pound 2x4 lumber | 80 feet per second (55 mph) | 22 $lb_f$ -s* |
| **FEMA 361 (Shelter Missile)** | 15 pound 2x4 lumber | 147 feet per second (100 mph) | 68 $lb_f$ -s* |

* $lb_f$ -s = pounds force per second

### 4.3.3.3 Windows and Skylights

This section addresses general design considerations for exterior windows and skylights. For additional information on windows and skylights located in hurricane-prone regions, see Section 4.3.3.4, and for those in tornado-prone regions, see Section 4.5.

For further general information on windows, see the National Institute of Building Sciences' *Building Envelope Design Guide* (www.wbdg.org/design/envelope.php).

#### Loads and Resistance

The IBC requires that windows, curtain walls, and skylight assemblies (i.e., the glazing, frame, and frame attachment to the wall or roof) have sufficient strength to resist the positive and negative design wind pressure (see Figure 4-43). Design professionals should specify that these assemblies comply with wind load testing in accordance with ASTM E 1233. It is important to specify an adequate load path and to check its continuity during submittal review.

Where water infiltration protection is particularly demanding and important, it is recommended that onsite water infiltration testing in accordance with ASTM E 1105 be specified.

**Figure 4-43:**
Two complete windows, including frames, blew out as a result of an inadequate number of fasteners. Typhoon Paka (Guam, 1997)

### Water Infiltration

Heavy rain accompanied by high winds can cause wind-driven water infiltration problems. The magnitude of the problem increases with the wind speed. Leakage can occur at the glazing/frame interface, the frame itself, or between the frame and wall. When the basic wind speed is greater than 120 mph, because of the very high design wind pressures and numerous opportunities for leakage path development, some leakage should be anticipated when the design wind speed conditions are approached.

The successful integration of windows and curtain walls into exterior walls is a challenge in protecting against water infiltration. To the extent possible when detailing the interface between the wall and the window or curtain wall units, designers should rely on sealants as the secondary line of defense against water infiltration, rather than making the sealant the primary protection. If a sealant joint is the first line of defense, a second line of defense should be designed to intercept and drain water that drives past the sealant joint.

> The maximum test pressure used in the current ASTM test standard for evaluating resistance of window units to wind-driven rain is well below design wind pressures. Therefore, units that demonstrate adequate wind-driven rain resistance during testing may experience leakage during actual wind events.

When designing joints between walls and windows and curtain wall units, consider the shape of the sealant joint (i.e., a square joint is typically preferred) and the type of sealant to be specified. The sealant joint should be designed to enable the sealant to bond on only two opposing surfaces (i.e., a backer rod or bond-breaker tape should be specified). Butyl is recommended as a sealant for concealed joints, and polyurethane for exposed joints. During installation, cleanliness of the sealant substrate is important (particularly if polyurethane or silicone sealants are specified), as is the tooling of the sealant. ASTM E 2112 provides guidance on the design of sealant joints, as well as other information pertaining to the installation of windows, including the use of sill pan flashings with end dams and rear legs (see Figure 4-44). Windows that do not have nailing flanges should typically be installed over a pan flashing. It is recommended that designers use ASTM E 2112 as a design resource.

Sealant joints can be protected with a removable stop, as illustrated in Figure 4-45. The stop protects the sealant from direct exposure to the weather and reduces the possibility of wind-driven rain penetration.

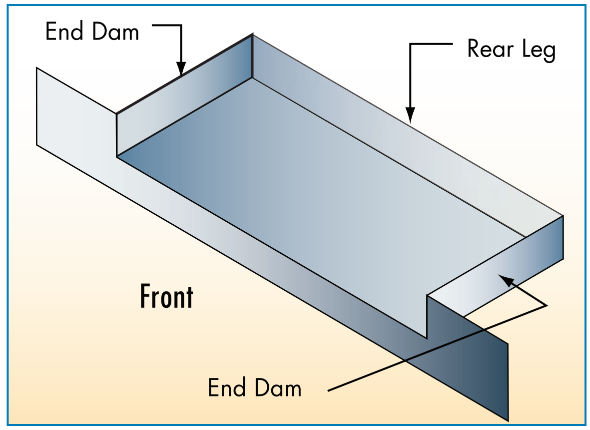



**Figure 4-44:**
View of a typical window sill pan flashing with end dams and rear legs
SOURCE: ASTM E 2112

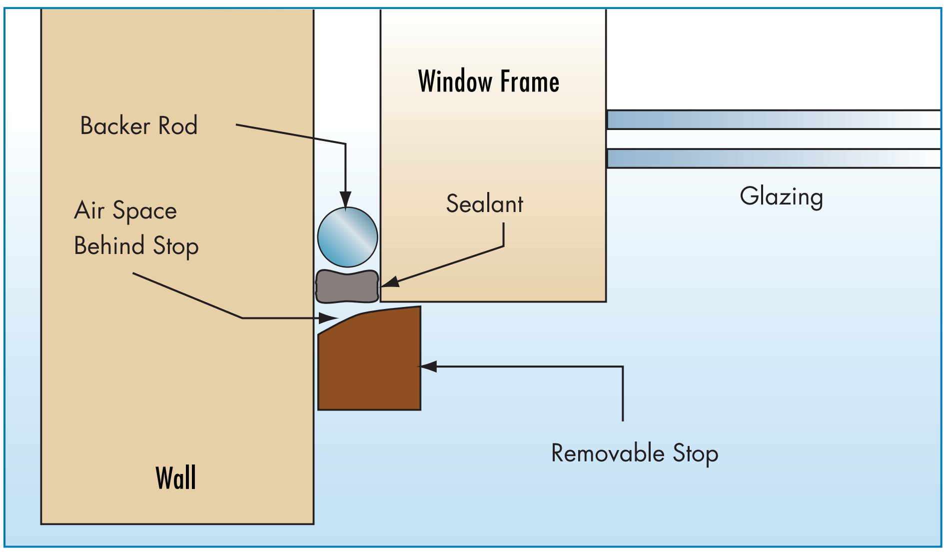



**Figure 4-45:**
Protecting sealant retards weathering and reduces the exposure to wind-driven rain.

## 4.3.3.4 Windows and Skylights in Hurricane-Prone Regions

Exterior glazing that is not impact-resistant (such as laminated glass or polycarbonate) or protected by shutters is extremely susceptible to breaking if struck by wind-borne debris. Even small, low-momentum missiles can easily break glazing that is not protected (see Figures 4-46 and 4-47). At the hospital shown in Figure 4-46, approximately 400 windows were broken. Most of the breakage was caused by wind-blown aggregate from the hospital's aggregate ballasted single-ply membrane roofs, and aggregate from built-up roofs. At the hospital shown in Figure 4-47, several of the skylight's tempered glass outer panes were broken by wind-blown aggregate from the hospital's aggregate ballasted single-ply membrane. The inner laminated glass panes were not broken. Note that some of the copings were also blown off (blue arrow)—some of the glazing may have been damaged by wind-blown copings. At the grey hospital on the other side of the street, much of the roof membrane was blown away (yellow arrow).

With broken windows, a substantial amount of water can be blown into a building, and the internal air pressure can be greatly increased, which may damage the interior partitions and ceilings.

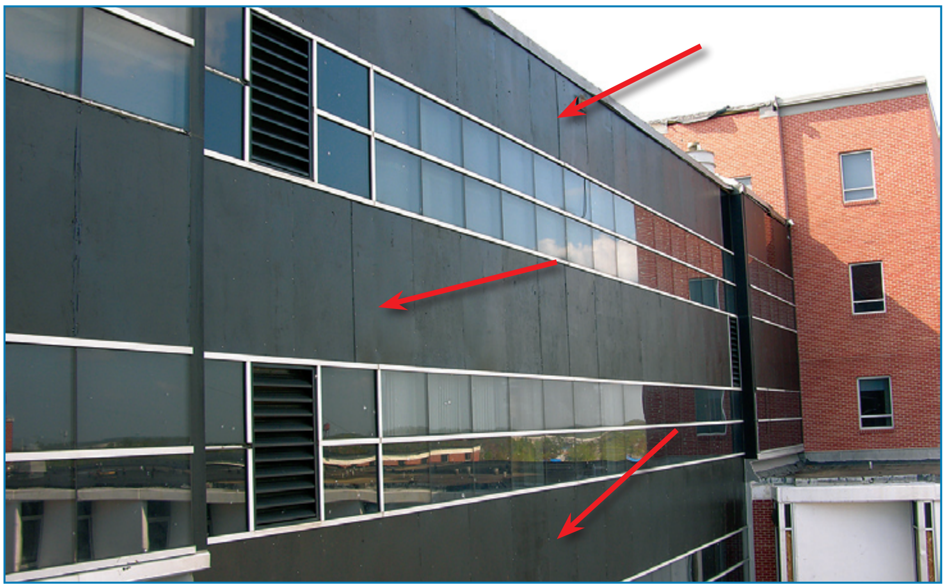


**Figure 4-46:** Plywood panels (black continuous bands) installed after the glass spandrel panels were broken by roof aggregate.[9] Hurricane Katrina (Mississippi, 2005)

**Figure 4-47:** The outer glass panes of the skylight were broken by roof aggregate (red arrow). Hurricane Hugo (South Carolina, 1989)

9 Glass spandrel panels are opaque glass. They are placed in curtain walls to conceal the area between the ceiling and the floor above.

In order to minimize interior damage, the IBC, through ASCE 7, prescribes that exterior glazing in wind-borne debris regions be impact-resistant, or be protected with an impact-resistant covering (shutters). For Category III and IV buildings in areas with a basic wind speed of 130 mph or greater, the glazing is required to resist a larger momentum test missile than would Category II buildings and Category III and IV buildings in areas with wind speeds of less than 130 mph.

ASCE 7 refers to ASTM E 1996 for missile loads and to ASTM E 1886 for the test method to be used to demonstrate compliance with the E 1996 load criteria. In addition to testing impact resistance, the window unit is subjected to pressure cycling after test missile impact to evaluate whether the window can still resist wind loads. If wind-borne debris glazing protection is provided by shutters, the glazing is still required by ASCE 7 to meet the positive and negative design air pressures.

Although the ASCE 7 wind-borne debris provisions only apply to glazing within a portion of hurricane-prone regions, it is recommended that all hospitals located where the basic wind speed is 100 mph or greater comply with the following recommendations:

- To minimize the potential for missiles penetrating exterior glazing and injuring people, it is recommended that exterior glazing up to 60 feet above grade be designed to resist the test Missile E load specified in ASTM E 1996 (see text box in Section 4.3.3.2). In addition, if roofs with aggregate surfacing are present within 1,500 feet of the facility, glazing above 60 feet should be designed to resist the test Missile A load specified in ASTM E 1996. The height of the protected glazing should extend a minimum of 30 feet above the aggregate surfaced roof per ASCE 7.

  Because large missiles are generally flying at lower elevations, glazing that is more than 60 feet above grade and meets the test Missile A load should be sufficient. However, if the facility is within a few hundred feet of another building that may create debris, such as EIFS, tiles, or rooftop equipment, it is recommended that the test Missile E load be specified instead of the Missile A for the upper-level glazing.

- For those facilities where glazing resistant to bomb blasts is desired, the windows and glazed doors can be designed to accommodate wind pressure, missile loads, and blast pressure. However, the window and door units need to be tested for missile loads and cyclic air pressure, as well as for blast. A unit that meets blast criteria will not necessarily meet the E 1996 and E 1886 criteria, and vice versa.

> For further information on designing glazing to resist blast, see the "Blast Safety" resource pages of the National Institute of Building Sciences' *Building Envelope Design Guide* (www.wbdg.org/design/envelope.php).

With the advent of building codes requiring glazing protection in windborne debris regions, a variety of shutter designs have entered the market. Shutters typically have a lower initial cost than laminated glass. However, unless the shutter is permanently anchored to the building (e.g., an accordion shutter), storage space will be needed. Also, when a hurricane is forecast, costs will be incurred each time shutters are installed and removed. The cost and difficulty of shutter deployment and demobilization on upper-level glazing may be avoided by using motorized shutters, although laminated glass may be a more economical solution. For further information on shutters, see Section 4.4.2.2.

### 4.3.3.5 Non-Load-Bearing Walls, Wall Coverings, and Soffits

> For further general information on non-load-bearing walls and wall coverings, see the National Institute of Building Sciences' *Building Envelope Design Guide* (www.wbdg.org/design/envelope.php).

This section addresses exterior non-load-bearing walls, exterior wall coverings, and soffits, as well as the underside of elevated floors, and provides guidance for interior non-load-bearing masonry walls. See Section 4.4.3.6 for additional information pertaining to hospitals located in hurricane-prone regions, and Section 4.5 for additional information pertaining to hospitals located in tornado-prone regions.

**Figure 4-48:** The wall covering blew off the penthouse at this hospital complex, allowing rainwater to destroy the elevator controls. Hurricane Ivan (Florida, 2004)

> To ensure the continuity of elevator service, elevator penthouse walls must possess adequate wind and water resistance. If the walls blow away or water leaks through the wall system, the elevator controls and/or motors can be destroyed. Loss of elevators may critically affect facility operations (see Figures 4-22 and 4-48). The restoration of elevator service can take weeks, even with expedited work.

### Loads and Resistance

The IBC requires that soffits, exterior non-load-bearing walls, and wall coverings have sufficient strength to resist the positive and negative design wind pressures.

**Soffits:** Depending on the wind direction, soffits can experience either positive or negative pressure. Besides the cost of repairing the damaged soffits, wind-borne soffit debris can cause property damage and injuries (see Figures 4-49 and 4-50). Failed soffits may also provide a convenient path for wind-driven rain to enter the building. Storm-damage research has shown that water blown into attic spaces after the loss of soffits can cause significant damage and the collapse of ceilings. Even in instances where soffits remain in place, water can penetrate through soffit vents and cause damage. At this time, there are no known specific test standards or design guidelines to help design wind- and water-resistant soffits and soffit vents.

> Where corrosion is a problem, stainless steel fasteners are recommended for wall and soffit systems. For other components (e.g., furring, blocking, struts, and hangers), nonferrous components (such as wood), stainless steel, or steel with a minimum of G-90 hot-dipped galvanized coating are recommended. Additionally, access panels are recommended so components within soffit cavities can be periodically inspected for corrosion or dry rot.

**Figure 4-49:**
This suspended metal soffit was not designed for upward-acting wind pressure. Typhoon Paka (Guam, 1997)

Figure 4-50:
Hospital canopy damage. Hurricane Katrina (Louisiana, 2005)

**Exterior non-load-bearing masonry walls:** Particular care should be given to the design and construction of exterior non-load-bearing masonry walls. Although these walls are not intended to carry gravity loads, they should be designed to resist the external and internal loading for components and cladding in order to avoid collapse. When these types of walls collapse, they represent a severe risk to life because of their great weight.

**Interior non-load-bearing masonry walls:** Special consideration should also be given to interior non-load-bearing masonry walls. Although these walls are not required by building codes to be designed to resist wind loads, if the exterior glazing is broken, or the exterior doors are blown away, the interior walls could be subjected to significant load as the building rapidly becomes fully pressurized. To avoid casualties, it is recommended that interior non-load-bearing masonry walls adjacent to occupied areas be designed to accommodate loads exerted by a design wind event, using the partially enclosed pressure coefficient (see Figure 4-51). By doing so, wall collapse may be prevented if the building envelope is breached. This recommendation is applicable to hospitals located in areas with a basic wind speed greater than 120 mph, and to hospitals in tornado-prone regions that do not have shelter space designed in accordance with FEMA 361.

Figure 4-51:
The red arrows show the original location of a CMU wall that nearly collapsed following a rolling door failure. Hurricane Charley (Florida, 2004)

### Wall Coverings

There are a variety of exterior wall coverings. Brick veneer, exterior insulation finish systems (EIFS), stucco, metal wall panels, and aluminum and vinyl siding have often exhibited poor wind performance. Veneers (such as ceramic tile and stucco) over concrete, stone veneer, and cement-fiber panels and siding have also blown off. Wood siding and panels rarely blow off. Although tilt-up precast walls have failed during wind storms, precast wall panels attached to steel or concrete framed buildings typically offer excellent wind performance.

**Brick veneer:**[10] Brick veneer is frequently blown off walls during high winds. When brick veneer fails, wind-driven water can enter and damage buildings, and building occupants can be vulnerable to injury from windborne debris (particularly if the walls are sheathed with plastic foam insulation or wood fiberboard in lieu of wood panels). Pedestrians in the vicinity of damaged walls can also be vulnerable to injury from falling bricks (see Figure 4-52). Common failure modes include tie (anchor) fastener pull-out (see Figure 4-53), failure of masons to embed ties into the mortar, poor bonding between ties and mortar, a mortar of poor quality, and tie corrosion.

10 The brick veneer discussion is from *Attachment of Brick Veneer in High-Wind Regions*—Hurricane Katrina Recovery Advisory (FEMA, December 2005).

**Figure 4-52:**
The brick veneer failure on this building was attributed to tie corrosion. Hurricane Ivan (Florida, 2004)

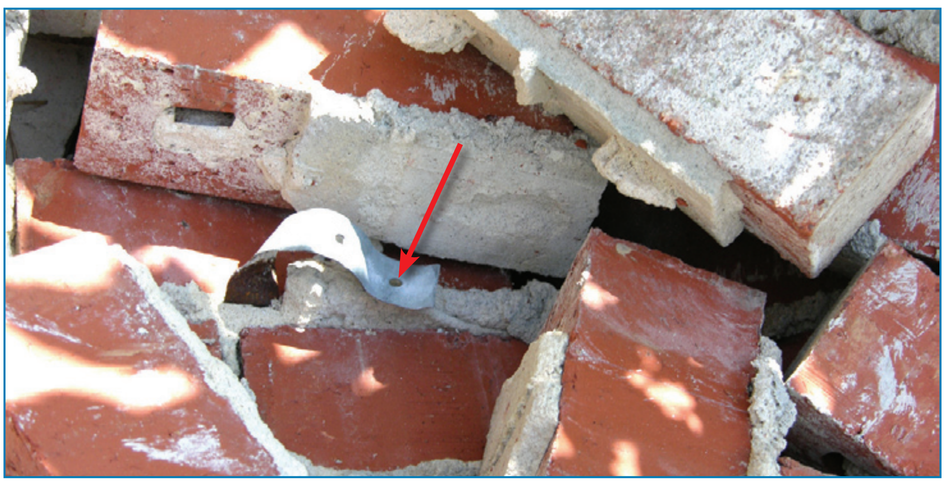


**Figure 4-53:**
This tie remained embedded in the mortar joint while the smooth-shank nail pulled from the stud.

Ties are often installed before brick laying begins. When this is done, ties are often improperly placed above or below the mortar joints. When misaligned, the ties must be angled up or down to be embedded into the mortar joints (Figure 4-54). Misalignment not only reduces the embedment depth, but also reduces the effectiveness of the ties, because wind forces do not act in parallel direction to the ties.

Corrugated ties typically used in residential veneer construction provide little resistance to compressive loads induced by positive and negative pressure. The use of compression struts would likely be beneficial, but off-the-shelf devices do not currently exist. Two-piece adjustable ties (Figure 4-55) provide significantly greater compressive strength than corrugated ties.

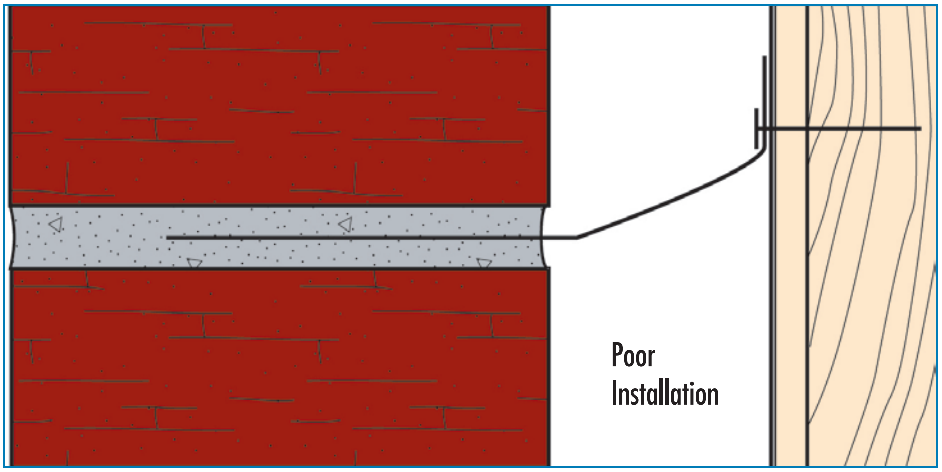



**Figure 4-54:** Misalignment of the tie reduces the embedment and promotes veneer failure.

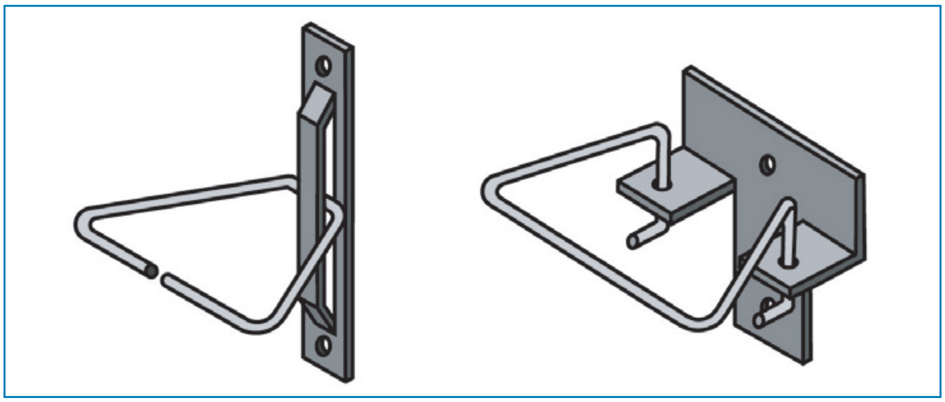


**Figure 4-55:** Examples of two-piece adjustable ties

The following Brick Industry Association (BIA) technical notes provide guidance on brick veneer: *Technical Notes 28: Anchored Brick Veneer, Wood Frame Construction* (2002); *Technical Notes 28B: Brick Veneer/Steel Stud Walls* (2005); and T*echnical Notes 44B: Wall Ties* (2003) (available online at www.bia.org). These technical notes provide attachment recommendations; however, they are not specific for high-wind regions. To enhance wind performance of brick veneer, the following are recommended:

- Calculate wind loads and determine tie spacing in accordance with the latest edition of the Building Code Requirements for Masonry Structures, ACI 530/ASCE 5/TMS 402 (ACI 530, 2005). A stud spacing of 16 inches on center is recommended so that ties can be anchored at this spacing.

- Ring-shank nails are recommended in lieu of smooth-shank nails for wood studs. A minimum embedment of 2 inches is suggested.

- For use with wood studs, two-piece adjustable ties are recommended. However, where corrugated steel ties are used, they should be 22-gauge minimum, 7/8-inch wide by 6-inch long, and comply with ASTM A 1008, with a zinc coating complying with ASTM A 153 Class B2. For ties used with steel studs, see BIA *Technical Notes 28B—Brick Veneer/Steel Stud Walls*. Stainless steel ties should be used for both wood and steel studs in areas within 3,000 feet of the coast.

❍ Install ties as the brick is laid so that the ties are properly aligned with the mortar joints.

❍ Locate ties within 8 inches of door and window openings, and within 12 inches of the top of veneer sections.

❍ Although corrugated ties are not recommended, if they are used, bend the ties at a 90-degree angle at the nail head to minimize tie flexing when the ties cycle between tension and compression loads (Figure 4-56).

❍ Embed ties in joints so that the mortar completely encapsulates the ties. Embed a minimum of 1½ inches into the bed joint, with a minimum mortar cover of 5/8-inch to the outside face of the wall (Figure 4-57).

**Figure 4-56:**
Bend ties at nail heads

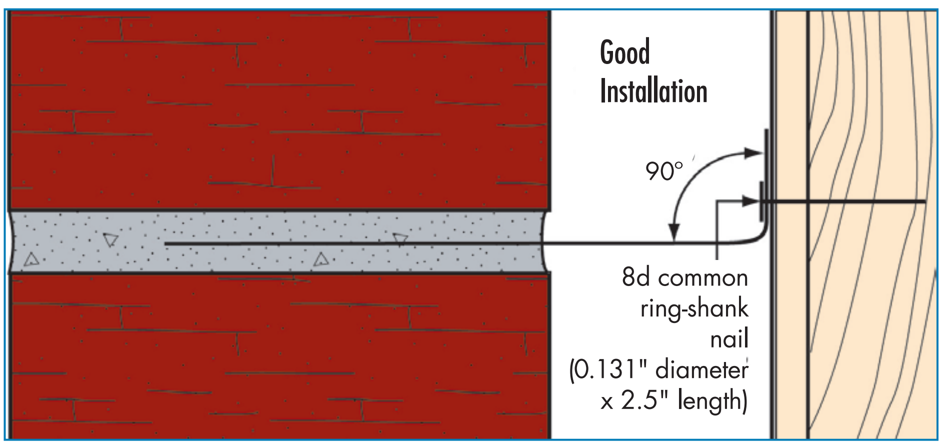
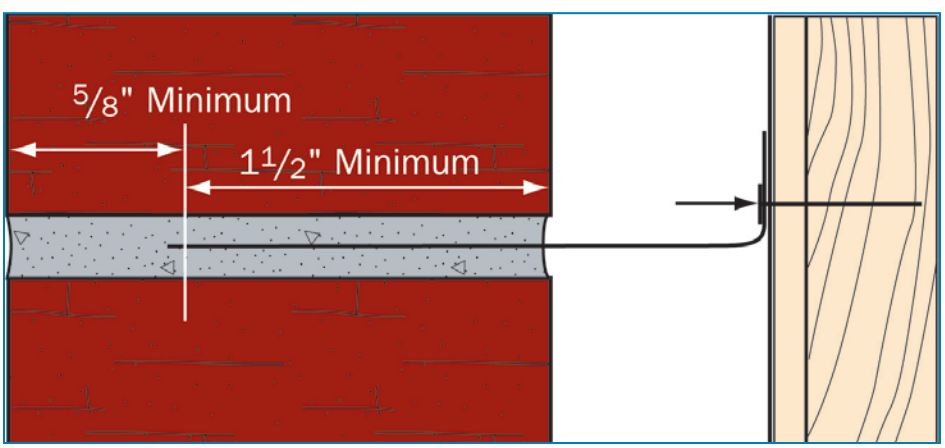



**Figure 4-57:**
Tie embedment



To avoid water leaking into the building, it is important that weep holes be adequately spaced and not be blocked during brick installation, and that through-wall flashings be properly designed and installed. When the base of the brick veneer occurs near grade, the grade should be designed so that it occurs several inches below the weeps so that drainage from the weeps is not impeded. Also, landscaping should be kept clear of weeps so that vegetation growth does not cause blockage of weeps. At the hospital shown in Figure 4-58, water leaked into the building along the base of many of the brick veneer walls. When high winds accompany heavy rain, a substantial amount of water can be blown into the wall cavity.

**Figure 4-58:**
Water leaked inside along the base of the brick veneer walls (red arrow). Hurricane Katrina (Louisiana, 2005)

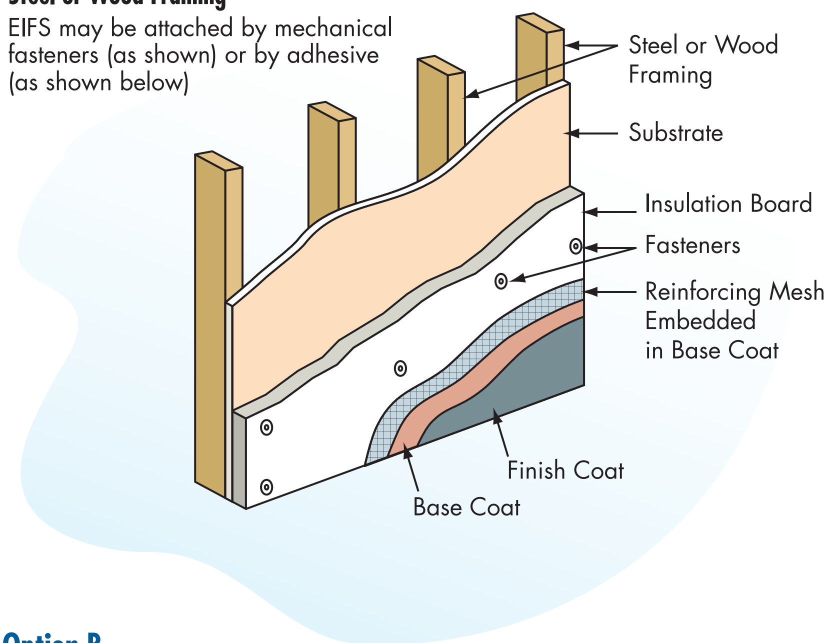
**EIFS:** Figure 4-59 shows typical EIFS assemblies. Figure 4-48 and several figures in Section 4.2.1.3 show EIFS blow-off. In these cases, the molded expanded polystyrene (MEPS) was attached to gypsum board, which in turn was attached to metal studs or hat channels. The gypsum board detached from the studs/hat channels, which is a common EIFS failure mode. When the gypsum board on the exterior side of the studs is blown away, it is common for gypsum board on the interior side to also be blown off. The opening allows the building to become fully pressurized and allows the entrance of wind-driven rain. Other common types of failure include wall framing failure, separation of the MEPS from its substrate, and separation of the synthetic stucco from the MEPS.

At the hospital shown in Figure 4-60, the EIFS was applied over a concrete wall. The MEPS debonded from the concrete. In general, a concrete substrate prevents wind and water from entering a building, but if the EIFS debonds from the concrete, EIFS debris can break unprotected glazing. Glazing damage can be very devastating, as shown and discussed in Section 4.2.1.3.

Figure 4-59:
Typical EIFS assemblies

### Option A

**Steel or Wood Framing**
EIFS may be attached by mechanical fasteners (as shown) or by adhesive (as shown below)




### Option B

**Concrete or Masonry**
EIFS attached to concrete or masonry using adhesive. Mechanical fasteners may also be used.

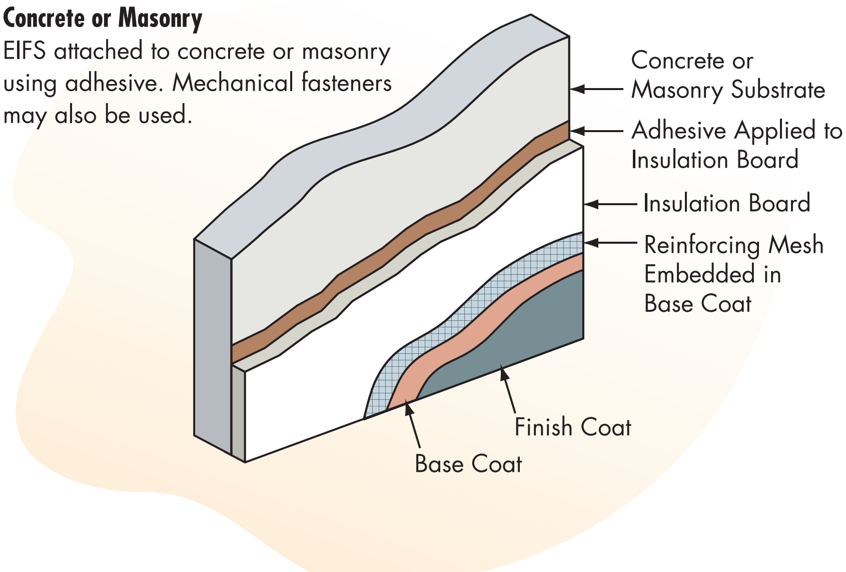


Figure 4-60:
EIFS blown off a cast-in-place concrete wall. Note the damaged rooftop ductwork. Hurricane Ivan (Florida, 2004)

Reliable wind performance of EIFS is very demanding on the designer and installer, as well as the maintenance of EIFS and associated sealant joints in order to minimize the reduction of EIFS' wind resistance due to water infiltration. It is strongly recommended that EIFS be designed with a drainage system that allows for the dissipation of water leaks. For further information on EIFS performance during high winds and design guidance, see FEMA 489 and 549.

Another issue associated with EIFS is the potential for judgment errors. EIFS applied over studs is sometimes mistaken for a concrete wall, which may lead people to seek shelter behind it. However, instead of being protected by several inches of concrete, only two layers of gypsum board (i.e., one layer on each side of the studs) and a layer of MEPS separate the occupants from the impact of wind-borne debris that can easily penetrate such a wall and cause injury.

**Stucco over studs:** Wind performance of traditional stucco walls is similar to the performance of EIFS, as shown in Figure 4-61. In several areas the metal stud system failed; in other areas the gypsum sheathing blew off the studs; and in other areas, the metal lath blew off the gypsum sheathing. The failure shown in Figure 4-61 illustrates the importance of designing and constructing wall framing (including attachment of stud tracks to the building and attachment of the studs to the tracks) to resist the design wind loads.

Figure 4-61:
The stucco wall failure was caused by inadequate attachment between the stud tracks and the building's structure. Hurricane Ivan (Florida, 2004)

**Metal wall panels:** Wind performance of metal wall panels is highly variable. Performance depends on the strength of the specified panel (which is a function of material and thickness, panel profile, panel width, and whether the panel is a composite) and the adequacy of the attachment (which can be by either concealed clips or exposed fasteners). Excessive spacing between clips/fasteners is the most common problem. Clip/fastener spacing should be specified, along with the specific type and size of fastener. Figure 4-62 illustrates metal wall panel problems. At this building, the metal panels were attached with concealed fasteners. The panels unlatched at the standing seams. In addition to generating wind-borne debris, loss of panels allowed wind-driven rain to enter the building. Water entry was facilitated by lack of a moisture barrier and solid sheathing behind the metal panels (as discussed below).

To minimize water infiltration at metal wall panel joints, it is recommended that sealant tape be specified at sidelaps when the basic wind speed is in excess of 90 mph. However, endlaps should be left unsealed so that moisture behind the panels can be wicked away. Endlaps should be a minimum of 3 inches (4 inches where the basic wind speed is greater than 120 mph) to avoid wind-driven rain infiltration. At the base of the wall, a 3-inch (4-inch) flashing should also be detailed, or the panels should be detailed to overlap with the slab or other components by a minimum of 3 inches (4 inches).

**Figure 4-62:**
The loss of metal wall panels allowed a substantial amount of wind-driven rain to penetrate this building. Hurricane Ivan (Florida, 2004)

The Vinyl Siding Institute (VSI) sponsors a Certified Installer Program that recognizes individuals with at least 1 year of experience who can demonstrate proper vinyl siding application. If vinyl siding is specified, design professionals should consider specifying that the siding contractor be a VSI-certified installer. For further information on this program, see www.vinylsiding.org.

**Vinyl siding:** Vinyl siding blow-off is typically caused by nails spaced too far apart and/or the use of vinyl siding that has inadequate wind resistance. Vinyl siding is available with enhanced wind resistance features, such as an enhanced nailing hem, greater interlocking area, and greater thickness.

**Secondary line of protection:** Almost all wall coverings permit the passage of some water past the exterior surface of the covering, particularly when the rain is wind-driven. For this reason, most wall coverings should be considered water-shedding, rather than waterproofing coverings. To avoid moisture-related problems, it is recommended that a secondary line of protection with a moisture barrier (such as housewrap or asphalt-saturated felt) and flashings around door and window openings be provided. Designers should specify that horizontal laps of the moisture barrier be installed so that water is allowed to drain from the wall (i.e., the top sheet should lap over the bottom sheet so that water running down the sheets remains on their outer surface). The bottom of the moisture barrier needs to be designed to allow drainage. Had the metal wall panels shown in Figure 4-62 been applied over a moisture barrier and sheathing, the amount of water entering the building would have likely been eliminated or greatly reduced.

In areas that experience frequent wind-driven rain, incorporating a rain screen design, by installing vertical furring strips between the moisture barrier and siding materials, will facilitate drainage of water from the space between the moisture barrier and backside of the siding. In areas that frequently experience strong winds, enhanced flashing is recommended. Enhancements include use of flashings that have extra-long flanges, and the use of sealant and tapes. Flashing design should recognize that wind-driven water could be pushed up vertically. The height to which water can be pushed increases with wind speed. Water can also migrate vertically and horizontally by capillary action between layers of materials (e.g., between a flashing flange and housewrap). Use of a rain screen design, in conjunction with enhanced flashing design, is recommended in areas that frequently experience wind-driven rain or strong winds. It is recommended that designers attempt to determine what type of flashing details have successfully been used in the area where the facility will be constructed.

#### Underside of Elevated Floors

If sheathing is applied to the underside of joists or trusses elevated on piles (e.g., to protect insulation installed between the joists/trusses), its attachment should be specified in order to avoid blow-off. Stainless steel or hot-dip galvanized nails or screws are recommended. Since ASCE 7 does not provide guidance for load determination, professional judgment in specifying attachment is needed.

### 4.3.3.6 Non-Load-Bearing Walls, Wall Coverings, and Soffits in Hurricane-Prone Regions

In order to achieve enhanced missile resistance of non-load-bearing exterior walls, the wall types discussed in Section 4.3.2.1 (i.e., reinforced concrete, or reinforced and fully grouted CMU) are recommended.

To minimize long-term problems with exterior wall coverings and soffits, it is recommended that they be avoided to the maximum extent possible. Exposed or painted reinforced concrete or CMU offers greater reliability (i.e., they have no coverings that can blow off and become wind-borne debris).

For all hospitals located where the basic wind speed is 100 mph or greater that are not constructed using reinforced concrete or reinforced and fully grouted CMU (as is recommended in this manual), it is recommended that the wall system selected be sufficient to resist complete penetration of the wall by the “E” missile specified in ASTM E 1996.

For interior non-load-bearing masonry walls in hospitals located where the basic wind speed is greater than 120 mph, see the recommendations given in Section 4.3.3.5.

### 4.3.3.7 Roof Systems

For further general information on roof systems, see the National Institute of Building Sciences' *Building Envelope Design Guide* (www.wbdg.org/design/envelope.php).

Because roof covering damage has historically been the most frequent and the costliest type of wind damage, special attention needs to be given to roof system design. See Section 4.3.3.8 for additional information pertaining to hospitals located in hurricane-prone regions, and Section 4.5 for hospitals located in tornado-prone regions.

#### Code Requirements

The IBC requires the load resistance of the roof assembly to be evaluated by one of the test methods listed in IBC's Chapter 15. Design professionals are cautioned that designs that deviate from the tested assembly (either with material substitutions or change in thickness or arrangement) may adversely affect the wind performance of the assembly. The IBC does not specify a minimum safety factor. However, for the roof system, a safety factor of 2 is recommended. To apply the safety factor, divide the test load by 2 to determine the allowable design load. Conversely, multiply the design load by 2 to determine the minimum required test resistance.

For structural metal panel systems, the IBC requires test methods UL 580 or ASTM E 1592. It is recommended that design professionals specify use of E 1592, because it gives a better representation of the system's uplift performance capability.

The roof of the elevator penthouse must possess adequate wind and water resistance to ensure continuity of elevator service. It is recommended that a secondary roof membrane, as discussed in Section 4.3.3.8, be specified over the elevator penthouse roof deck.

#### Load Resistance

Specifying the load resistance is commonly done by specifying a Factory Mutual Research (FMR) rating, such as FM 1-75. The first number (1) indicates that the roof assembly passed the FMR tests for a Class 1 fire rating. The second number (75) indicates the uplift resistance in pounds per square foot (psf) that the assembly achieved during testing. With a safety factor of two this assembly would be suitable for a maximum design uplift load of 37.5 psf.

The highest uplift load occurs at the roof corners because of building aerodynamics as discussed in Section 4.1.3. The perimeter has a somewhat lower load, while the field of the roof has the lowest load. FMG Property Loss Prevention Data Sheets are formatted so that a roof assembly can be selected for the field of the roof. For the perimeter and corner areas, FMG Data Sheet 1-29 provides three options: 1) use the FMG *Approval Guide* listing if it includes a perimeter and corner fastening method; 2) use a roof system with the appropriate FMG Approval rating in the field, perimeter, and corner, in accordance with Table 1 in FMG Data Sheet 1-29; or 3) use prescriptive recommendations given in FMG Data Sheet 1-29.

When perimeter and corner uplift resistance values are based on a prescriptive method rather than testing, the field assembly is adjusted to meet the higher loads in the perimeter and corners by increasing the number of fasteners or decreasing the spacing of adhesive ribbons by a required amount. However, this assumes that the failure is the result of the fastener pulling out from the deck, or that the failure is in the vicinity of the fastener plate, which may not be the case. Also, the increased number of fasteners required by FMG may not be sufficient to comply with the perimeter and corner loads derived from the building code. Therefore, if FMG resistance data are specified, it is prudent for the design professional to specify the resistance for each zone of the roof separately. Using the example cited above, if the field of the roof is specified as 1-75, the perimeter would be specified as 1-130 and the corner would be specified as 1-190.

If the roof system is fully adhered, it is not possible to increase the uplift resistance in the perimeter and corners. Therefore, for fully adhered systems, the uplift resistance requirement should be based on the corner load rather than the field load.

> FM Global (FMG) is the name of the Factory Mutual Insurance Company and its affiliates. One of FMG's affiliates, Factory Mutual Research (FMR) provides testing services, produces documents that can be used by designers and contractors, and develops test standards for construction products and systems. FMR evaluates roofing materials and systems for resistance to fire, wind, hail, water, foot traffic and corrosion. Roof assemblies and components are evaluated to establish acceptable levels of performance. Some documents and activities are under the auspices of FMG and others are under FMR.

### Roof System Performance

Storm-damage research has shown that sprayed polyurethane foam (SPF) and liquid-applied roof systems are very reliable high-wind performers. If the substrate to which the SPF or liquid-applied membrane is applied does not lift, it is highly unlikely that these systems will blow off. Both systems are also more resistant to leakage after missile impact damage than most other systems. Built-up roofs (BURs) and modified bitumen systems have also demonstrated good wind performance provided the edge flashing/coping does not fail (which happens frequently). The exception is aggregate surfacing, which is prone to blow-off (see Figures 4-10 and 4-81). Modified bitumen applied to a concrete deck has demonstrated excellent resistance to progressive peeling after blow-off of the metal edge flashing. Metal panel performance is highly variable. Some systems are very wind-resistant, while others are quite vulnerable.

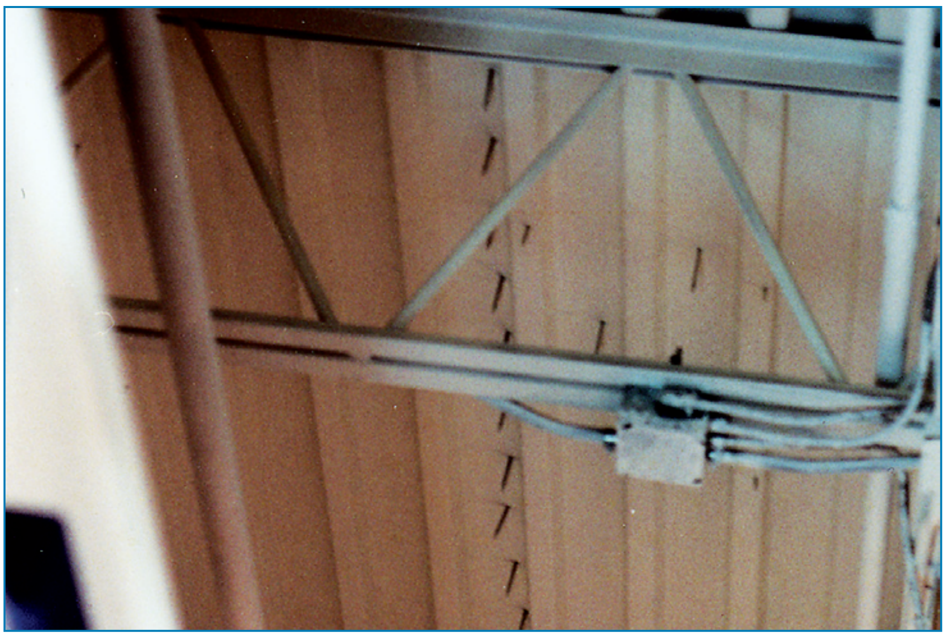
Of the single-ply attachment methods, the paver-ballasted and fully adhered methods are the least problematic. Systems with aggregate ballast are prone to blow-off, unless care is taken in specifying the size of aggregate and the parapet height (see Figures 4-5, 4-46, and 4-47). The performance of protected membrane roofs (PMRs) with a factory-applied cementitious coating over insulation boards is highly variable. When these boards are installed over a loose-laid membrane, it is critical that an air retarder be incorporated to prevent the membrane from ballooning and disengaging the boards. ANSI/SPRI RP-4 (which is referenced in the IBC) provides wind guidance for ballasted systems using aggregate, pavers, and cementitious-coated boards.

The National Research Council of Canada, Institute for Research in Construction's *Wind Design Guide for Mechanically Attached Flexible Membrane Roofs* (B1049, 2005) provides recommendations related to mechanically attached single-ply and modified bituminous systems. B1049 is a comprehensive wind design guide that includes discussion on air retarders. Air retarders can be effective in reducing membrane flutter, in addition to being beneficial for use in ballasted single-ply systems. When a mechanically attached system is specified, careful coordination with the structural engineer in selecting deck type and thickness is important.

If a steel deck is selected, it is critical to specify that the membrane fasteners be attached in rows perpendicular to the steel flanges to avoid overstressing the attachment of the deck to the deck support structure. At the building shown in Figure 4-63, the fastener rows of the mechanically attached single-ply membrane ran parallel to the top flange of the steel deck. The deck fasteners were overstressed and a portion of the deck blew off and the membrane progressively tore. At another building, shown in Figure 4-64, the membrane fastener rows also ran parallel to the top flange of the steel deck. When membrane fasteners run parallel to the flange, the flange with membrane fasteners essentially carries the entire uplift load because of the deck's inability to transfer any significant load to adjacent flanges. Hence, at the joists shown in Figure 4-64, the deck fasteners on either side of the flange with the membrane fasteners are the only connections to the joist that are carrying substantial uplift load.

Figure 4-63:
The orientation of the membrane fastener rows led to blow-off of the steel deck. Hurricane Marilyn (U.S. Virgin Islands, 1995)

Figure 4-64:
View of the underside of a steel deck showing the mechanically attached single-ply membrane fastener rows running parallel to, instead of across, the top flange of the deck.



For metal panel roof systems, the following are recommended:

- When clip or panel fasteners are attached to nailers, detail the connection of the nailer to the nailer support (including the detail of where nailers are spliced over a support).
- When clip or panel fasteners are loaded in withdrawal (tension), screws are recommended in lieu of nails.
- For concealed clips over a solid substrate, it is recommended that chalk lines be specified so that the clips are correctly spaced.

- When the basic wind speed is 110 mph or greater, it is recommended that two clips be used along the eaves, ridges, and hips.

- For copper panel roofs in areas with a basic wind speed greater than 90 mph, it is recommended that Type 316 stainless steel clips and stainless steel screws be used in lieu of copper clips.

- Close spacing of fasteners is recommended at hip and ridge flashings (e.g., spacing in the range of 3 to 6 inches on center, commensurate with the design wind loads.)

### Edge Flashings and Copings

Roof membrane blow-off is almost always a result of lifting and peeling of the metal edge flashing or coping, which serves to clamp down the membrane at the roof edge. Therefore, it is important for the design professional to carefully consider the design of metal edge flashings, copings, and the nailers to which they are attached. The metal edge flashing on the modified bitumen membrane roof shown in Figure 4-65 was installed underneath the membrane, rather than on top of it, and then stripped in. In this location, the edge flashing was unable to clamp the membrane down. At one area, the membrane was not sealed to the flashing. An ink pen was inserted into the opening prior to photographing to demonstrate how wind could catch the opening and lift and peel the membrane.

Figure 4-65:
The ink pen shows an opening that the wind can catch, and cause lifting and peeling of the membrane.

ANSI/SPRI ES-1, *Wind Design Standard for Edge Systems Used in Low Slope Roofing Systems* (2003) provides general design guidance including a methodology for determining the outward-acting load on the vertical flange of the flashing/coping (ASCE 7 does not provide this guidance).

ANSI/SPRI ES-1 is referenced in the IBC. ANSI/SPRI ES-1 also includes test methods for assessing flashing/coping resistance. This manual recommends a minimum safety factor of 3 for edge flashings, copings, and nailers for hospitals. For FMG-insured facilities, FMR-approved flashing should be used and FM Data Sheet 1-49 should also be consulted.

The traditional edge flashing/coping attachment method relies on concealed cleats that can deform under wind load and lead to disengagement of the flashing/coping (see Figure 4-66) and subsequent lifting and peeling of the roof membrane. When a vertical flange disengages and lifts up, the edge flashing and membrane are very susceptible to failure. Normally, when a flange lifts the failure continues to propagate and the metal edge flashing and roof membrane blows off.

Storm-damage research has revealed that, in lieu of cleat attachment, the use of exposed fasteners to attach the vertical flanges of copings and edge flashings has been found to be a very effective and reliable attachment method. The coping shown in Figure 4-67 was attached with $\frac{1}{4}$-inch diameter stainless steel concrete spikes at 12 inches on center. When the fastener is placed in wood, #12 stainless steel screws with stainless steel washers are recommended. The fasteners should be more closely spaced in the corner areas (the spacing will depend upon the design wind loads). ANSI/SPRI ES-1 provides guidance on fastener spacing and thickness of the coping and edge flashing.

**Figure 4-66:** The metal edge flashing on this hospital disengaged from the continuous cleat and the vertical flange lifted. Hurricane Hugo (South Carolina, 1989)

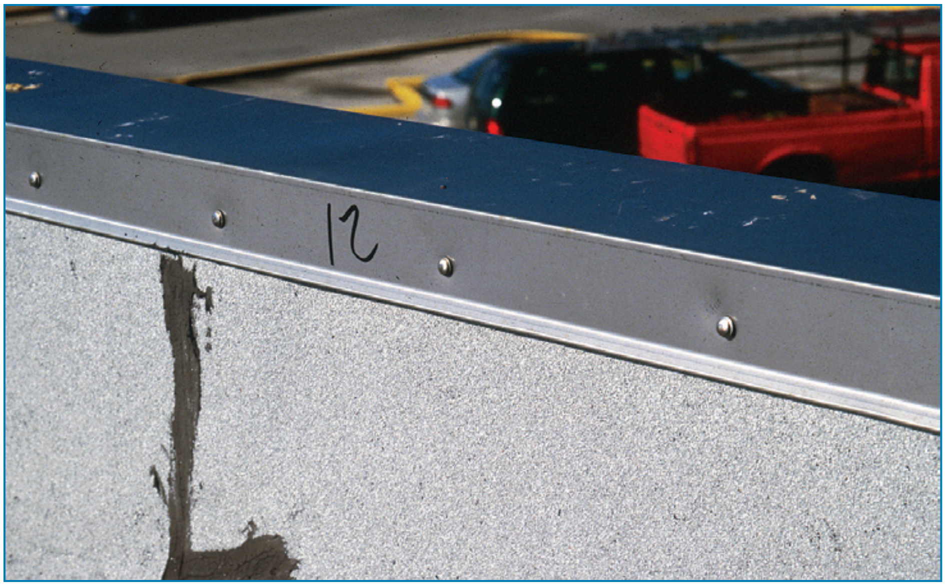



Figure 4-67:
Both vertical faces of the coping were attached with exposed fasteners instead of concealed cleats. Typhoon Paka (Guam, 1997)

### Gutters

Storm-damage research has shown that gutters are seldom constructed to resist wind loads (see Figure 4-68). When a gutter lifts, it typically causes the edge flashing that laps into the gutter to lift as well. Frequently, this results in a progressive lifting and peeling of the roof membrane. The membrane blow-off shown in Figure 4-69 was initiated by gutter uplift. The gutter was similar to that shown in Figure 4-68. The membrane blow-off caused significant interior water damage.

Figure 4-68:
This gutter, supported by a type of bracket that provides no significant uplift resistance, failed when wind lifted it, together with the metal edge flashing that lapped into the gutter. Hurricane Francis (Florida, 2004)

Figure 4-69:
The original modified bitumen membrane was blown away after the gutter lifted in the area shown by the red arrow (the black membrane is a temporary roof). Hurricane Francis (Florida, 2004)

Special design attention needs to be given to attaching gutters to prevent uplift, particularly for those in excess of 6 inches in width. Currently, there are no standards pertaining to gutter wind resistance. It is recommended that the designer calculate the uplift load on gutters using the overhang coefficient from ASCE 7. There are two approaches to resist gutter uplift.

- Gravity-support brackets can be designed to resist uplift loads. In these cases, in addition to being attached at its top, the bracket should also be attached at its low end to the wall. The gutter also needs to be designed so it is attached securely to the bracket in a way that will effectively transfer the gutter uplift load to the bracket. Bracket spacing will depend on the gravity and uplift load, the bracket's strength, and the strength of connections between the gutter/bracket and the bracket/wall. With this option, the bracket's top will typically be attached to a wood nailer, and that fastener will be designed to carry the gravity load. The bracket's lower connection will resist the rotational force induced by gutter uplift. Because brackets are usually spaced close together to carry the gravity load, developing adequate connection strength at the lower fastener is generally not difficult.

- The other option is to use gravity-support brackets only to resist gravity loads, and use separate sheet-metal straps at 45-degree angles to the wall to resist uplift loads. Strap spacing will depend on the gutter uplift load and strength of the connections between the gutter/strap and the strap/wall. Note that FMG Data Sheet 1-49 recommends placing straps 10 feet apart. However, at that spacing with wide gutters, fastener loads induced by uplift are quite high. When straps are spaced at 10 feet, it can be difficult to achieve sufficiently strong uplift connections.

When designing a bracket's lower connection to a wall or a strap's connection to a wall, designers should determine appropriate screw pull-out values. With this option, a minimum of two screws at each end of a strap is recommended. At a wall, screws should be placed side by side, rather than vertically aligned, so the strap load is carried equally by the two fasteners. When fasteners are vertically aligned, most of the load is carried by the top fastener.

Since the uplift load in the corners is much higher than the load between the corners, enhanced attachment is needed in corner areas regardless of the option chosen. ASCE 7 provides guidance about determining a corner area's length.

### Parapet Base Flashings

Information on loads for parapet base flashings was first introduced in the 2002 edition of ASCE 7. The loads on base flashings are greater than the loads on the roof covering if the parapet's exterior side is air-permeable. When base flashing is fully adhered, it has sufficient wind resistance in most cases. However, when base flashing is mechanically fastened, typical fastening patterns may be inadequate, depending on design wind conditions (see Figure 4-70). Therefore, it is imperative that the base flashing loads be calculated, and attachments designed to accommodate these loads. It is also important for designers to specify the attachment spacing in parapet corner regions to differentiate them from the regions between corners.

**Figure 4-70:** If mechanically attached base flashings have an insufficient number of fasteners, the base flashing can be blown away. Hurricane Andrew (Florida, 1992)

When the roof membrane is specified to be adhered, it is recommended that fully adhered base flashings be specified in lieu of mechanically attached base flashings. Otherwise, if the base flashing is mechanically attached, ballooning of the base flashing during high winds can lead to lifting and progressive peeling of the roof membrane.

### Steep-Slope Roof Coverings

For a discussion of wind performance of asphalt shingle and tile roof coverings, see FEMA 488 (2005), 489 (2005), and 549 (2006). For recommendations pertaining to asphalt shingles and tiles, see Fact Sheets 19, 20, and 21 in FEMA 499 (2005).

## 4.3.3.8 Roof Systems in Hurricane-Prone Regions

The following types of roof systems are recommended for hospitals in hurricane-prone regions, because they are more likely to avoid water infiltration if the roof is hit by wind-borne debris, and also because these systems are less likely to become sources of wind-borne debris:

- In tropical climates where insulation is not needed above the roof deck, specify either liquid-applied membrane over cast-in-place concrete deck, or modified bitumen membrane torched directly to primed cast-in-place concrete deck.

- Install a secondary membrane over a concrete deck (if another type of deck is specified, a cover board may be needed over the deck). Seal the secondary membrane at perimeters and penetrations. Specify rigid insulation over the secondary membrane. Where the basic wind speed is up to 110 mph, a minimum 2-inch thick layer of insulation is recommended. Where the speed is between 110 and 130 mph, a total minimum thickness of 3 inches is recommended (installed in two layers). Where the speed is greater than 130 mph, a total minimum thickness of 4 inches is recommended (installed in two layers). A layer of $\frac{5}{8}$-inch thick glass mat gypsum roof board is recommended over the insulation, followed by a modified bitumen membrane. A modified bitumen membrane is recommended for the primary membrane because of its somewhat enhanced resistance to puncture by small missiles compared with other types of roof membranes.

- When fully adhering boards to concrete decks, it is recommended that a planar flatness of a maximum of $\frac{1}{4}$-inch variation over a 10 foot length (when measured by a straightedge) be specified. Prior to installation of the roof insulation, it is recommended that the planar flatness be checked with a straightedge. If the deck is outside of the

$\frac{1}{4}$-inch variation, it is recommended that the high spots be ground or the low spots be suitably filled.

- The purpose of the insulation and gypsum roof board is to absorb missile energy. If the primary membrane is punctured or blown off during a storm, the secondary membrane should provide watertight protection unless the roof is hit with missiles of very high momentum that penetrate the insulation and secondary membrane. Figure 4-72 illustrates the merit of specifying a secondary membrane. The copper roof blew off the hospital's intensive care unit (ICU). Patients and staff were frightened by the loud noise generated by the metal panels as they banged around during the hurricane. Fortunately there was a very robust underlayment (a built-up membrane) that remained in place. Since only minor leakage occurred, the ICU continued to function.

When fully adhering insulation boards, it is recommended that the boards be no larger than 4 feet by 4 feet. It is also recommended that the board thickness not exceed 2 inches ( $1\frac{1}{2}$ inches is preferable). Use of small thin boards makes it easier for the contractor to conform the boards to the substrate. At the hospital shown in Figure 4-71, 4 foot by 8 foot insulation boards were set in hot asphalt over a concrete deck. A few of the boards detached from the deck. The boards may have initiated the membrane blow off, or the membrane blow off may have been initiated by lifting and peeling of the metal edge flashing, in which case, loss of the insulation boards was a secondary failure.

**Figure 4-71:** The blown off insulation (red arrow) may have initiated blow off of the roof membrane. Hurricane Ivan (Florida, 2004)

Figure 4-72:
The secondary membrane prevented leakage into the ICU after the copper roof blew off. Hurricane Andrew (Florida, 1992)

- For an SPF roof system over a concrete deck, where the basic wind speed is less than 130 mph, it is recommended that the foam be a minimum of 3 inches thick to avoid missile penetration through the entire layer of foam. Where the speed is greater than 130 mph, a 4-inch minimum thickness is recommended. It is also recommended that the SPF be coated, rather than protected with an aggregate surfacing.

- For a PMR, it is recommended that pavers weighing a minimum of 22 psf be specified. In addition, base flashings should be protected with metal (such as shown in Figure 4-79) to provide debris protection. Parapets with a 3-foot minimum height (or higher if so indicated by ANSI/SPRI RP-4, 2002) are recommended at roof edges. This manual recommends that PMRs not be used for hospitals in hurricane-prone regions where the basic wind speed exceeds 130 mph.

- For structural metal roofs, it is recommended that a roof deck be specified, rather than attaching the panels directly to purlins as is commonly done with pre-engineered metal buildings. If panels blow off buildings without roof decking, wind-borne debris and rain are free to enter the building.

  Structural standing seam metal roof panels with concealed clips and mechanically seamed ribs spaced at 12 inches on center are recommended. If the panels are installed over a concrete deck, a modified bitumen secondary membrane is recommended if the deck has a slope less than ½:12. If the panels are installed over a steel deck or wood sheathing, a modified bitumen secondary membrane (over a suitable cover board when over steel decking) is recommend, followed by rigid insulation and metal panels. Where the basic wind speed is up to 110 mph, a minimum 2-inch-thick layer of insulation is recommended. Where the speed is between 110 and 130 mph, a total minimum thickness of 3 inches is recommended. Where the speed is greater than 130 mph, a total minimum thickness of 4 inches is recommended. Although some clips are designed to bear on insulation, it is recommended that the panels be attached to wood nailers attached to the deck, because nailers provide a more stable foundation for the clips.

If the metal panels are blown off or punctured during a hurricane, the secondary membrane should provide watertight protection unless the roof is hit with missiles of very high momentum. At the roof shown in Figure 4-73, the structural standing seam panel clips bore on rigid insulation over a steel deck. Had a secondary membrane been installed over the steel deck, the membrane would have likely prevented significant interior water damage and facility disruption.

**Figure 4-73:** Significant interior water damage and facility interruption occurred after the standing seam roof blew off. Hurricane Marilyn (U.S. Virgin Islands, 1995)

- Based on field performance of architectural metal panels in hurricane-prone regions, exposed fastener panels are recommended in lieu of architectural panels with concealed clips. For panel fasteners, stainless steel screws are recommended. A secondary membrane protected with insulation is recommended, as discussed above for structural standing seam systems.

In order to avoid the possibility of roofing components blowing off and striking people arriving at a hospital during a storm, the following roof systems are not recommended: aggregate surfacings, either on BUR, single-plies or SPF; lightweight concrete pavers; cementitious-coated insulation boards; slate; and tile (see Figure 4-74). Even when slates and tiles are properly attached to resist wind loads, their brittleness makes them vulnerable to breakage as a result of wind-borne debris impact. The tile and slate fragments can be blown off the roof, and fragments can damage other parts of the roof, causing a cascading failure.

Figure 4-74:
Brittle roof coverings, like slate and tile, can be broken by missiles, and tile debris can break other tiles. Hurricane Charley (Florida, 2004)

Mechanically attached and air-pressure equalized single-ply membrane systems are susceptible to massive progressive failure after missile impact, and are therefore not recommended for hospitals in hurricane-prone regions. At the building shown in Figure 4-75, a missile struck the fully adhered low-sloped roof and slid into the steep-sloped reinforced mechanically attached single-ply membrane in the vicinity of the red arrow. A large area of the mechanically attached membrane was blown away as a result of progressive membrane tearing. Fully adhered single-ply membranes are very vulnerable to missile puncture and are not recommended unless they are ballasted with pavers. At the hospital shown in Figure 4-76, several missiles, including exhaust fans and copings struck the roof.

**Figure 4-75:** Mechanically attached single-ply membrane progressively tore after being cut by wind-borne debris. Hurricane Andrew (Florida, 1992)

**Figure 4-76:** This fully adhered single-ply roof membrane was struck by a variety of missiles. Hurricane Marilyn (U.S. Virgin Islands, 1995)

**Edge flashings and copings:** If cleats are used for attachment, it is recommended that a "peel-stop" bar be placed over the roof membrane near the edge flashing/coping, as illustrated in Figure 4-77. The purpose of the bar is to provide secondary protection against membrane lifting and peeling in the event that edge flashing/coping fails. A robust bar specifically made for bar-over mechanically attached single-ply systems is recommended. The bar needs to be very well anchored to the parapet or the deck. Depending on design wind loads, spacing between 4 and 12 inches on center is recommended. A gap of a few inches should be left between each bar to allow for water flow across the membrane. After the bar is attached, it is stripped over with a stripping ply.

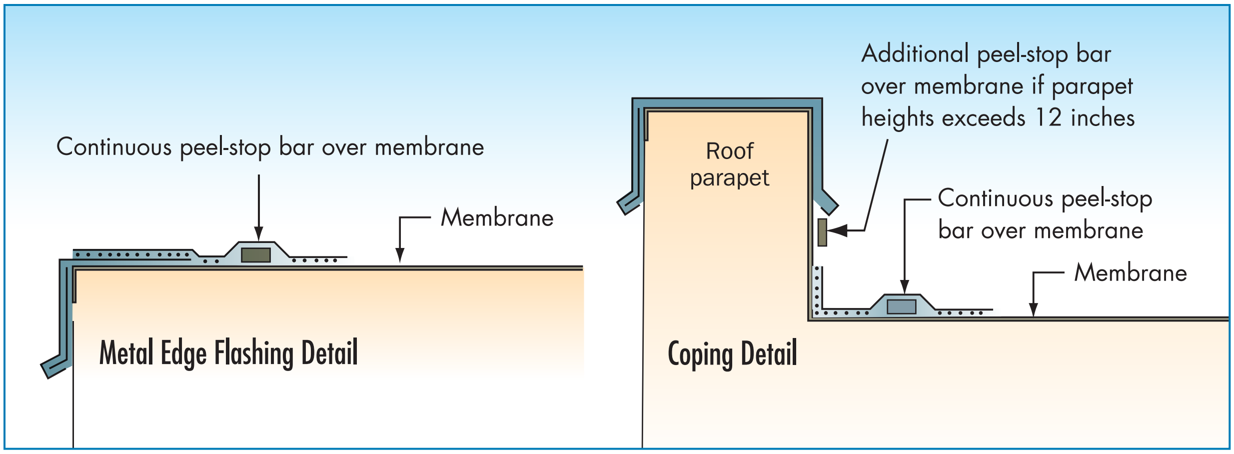



Figure 4-77:
A continuous peel-stop bar over the membrane may prevent a catastrophic progressive failure if the edge flashing or coping is blown off. (Modified from FEMA 55, 2000)

**Walkway pads:** Roof walkway pads are frequently blown off during hurricanes (Figures 4-78 and 4-82). Pad blow-off does not usually damage the roof membrane. However, wind-borne pad debris can damage other building components and injure people. Currently there is no test standard to evaluate uplift resistance of walkway pads. Walkway pads are therefore not recommended in hurricane-prone regions.

Figure 4-78:
Several rubber walkway pads were blown off the single-ply membrane roof on this hospital. Hurricane Katrina (Mississippi, 2005)

**Parapets:** For low-sloped roofs, minimum 3-foot high parapets are recommended. With parapets of this height or greater, the uplift load in the corner region is substantially reduced (ASCE 7 permits treating the corner zone as a perimeter zone). Also, a high parapet (as shown in Figures 4- 96) may intercept wind-borne debris and keep it from blowing off the roof and damaging other building components or injuring people. To protect base flashings from wind-borne debris damage and subsequent water leakage, it is recommended that metal panels on furring strips be installed over the base flashing (Figure 4-79). Exposed stainless steel screws are recommended for attaching the panels to the furring strips, because using exposed fasteners is more reliable than using concealed fasteners or clips (as were used for the failed panels shown in Figure 4-62).

**Figure 4-79:** Base flashing protected by metal panels attached with exposed screws. Hurricane Katrina (Mississippi, 2005)

### 4.3.3.9 The Case of DeSoto Memorial Hospital, Arcadia, Florida

The case of DeSoto Memorial Hospital illustrates damage caused by aggregate-surfaced roofs. The 82-bed hospital is located just off Florida Highway 17 in Arcadia, approximately 30 miles east of Florida's gulf coast. The hospital was constructed in 1964, though the current emergency room (ER), ICU, and third floor patient rooms were added in 1984. A separate pre-engineered storage building was constructed in 1979.

The facility was struck by Hurricane Charley in 2004, with an estimated peak gust wind speed between 125 to 140 mph.[11] Since the design wind speed in the 2005 edition of ASCE 7 for this location is 110 mph, the esti-

11 The 125 to 140 mph speeds were estimated for Exposure C.

mated speeds at this site were above current design conditions. Also, even with the 1.15 importance factor, the actual wind pressures were above the design pressures.

The hospital sustained damage to windows, rooftop equipment, and a freestanding storage building on the campus. Thirty-three windows were broken, including patient room windows and windows at three of the eight ICU rooms (Figures 4-80 and 4-81). Windows were also broken in many vehicles in the parking lot. The majority of the glass breakage was caused by aggregate blown from the hospital built-up roofs. Some of the glass breakage may have been due to blown-off gutters and walkway pads from the hospital's roof (Figure 4-82) or other missiles such as tree limbs; blown off gutters can be high-momentum missiles that can travel a substantial distance (see Figure 4-81).

As a result of the window breakage the entire ICU was evacuated during the hurricane and closed for about 2 weeks before repairs were completed and the unit reoccupied. Some patients were moved to lower floors; the elevator could not be used so the patients were either carried down or slid down the stairs on mattresses. Fortunately, no one was injured during the evacuation.

A portion of the roof covering was blown off and the satellite dish was nearly blown off too. The LPS was displaced in a few areas (see Figure 4-83). As a result of the damage to the roof covering and to rooftop equipment, water leaked into the building in several areas, which caused the closing of the operating room (OR), sterile processing, portions of the lab, and numerous offices. The OR was temporarily relocated to the Caesarian section (C-section) room. It was about a month before the OR was repaired and reoccupied.

The metal storage building that contained the hospital's supplies, maintenance shop, environmental services, and shipping and receiving collapsed, and its loss was significant for the hospital operations. Almost all of the tools and stock materials for repairs were lost (Figure 4-84). Tents were set up after the hurricane to provide storage. Because of subsequent storms in the next several weeks (including two hurricanes), the stored items had to be moved in and out of the tents on several occasions.

Municipal power and water were lost during the hurricane. The hospital ran on its generators for about 5 days before power was restored. Municipal water service was out for about 2 weeks, but fortunately the hospital had a secondary well for potable water, so water service was not interrupted.

Access to the hospital was not hampered by fallen trees or by flooding. However, some staff and emergency medical service (EMS) personnel were unable to get to the hospital quickly after the storm because of downed trees or floodwaters in their neighborhoods. Landline telephone service was not lost, but paging and cell phone services were. The homes of many staff members were no longer habitable after the storm, so tents were set up on the hospital campus to house staff and volunteers that came to provide assistance. This in turn required additional security services and shower and laundry facilities.

The hospital did not have a contingency plan to cope with the damages, and therefore, did not have pre-arranged contracts with contractors to perform inspections and emergency repairs. Fortunately, there were no problems finding contractors quickly after the storm, although the building materials needed for repairs were in short supply.


**Figure 4-80:** The second floor beyond the canopy houses the ICU. Several windows along the two ICU walls that are visible were broken.

Figure 4-81:
A view of the ICU from the third floor roof. The gutters (red arrow) are from the back side of the third floor roof.

Figure 4-82:
View of the back side of the third floor roof where the gutter and an asphalt plank walkway pad were blown away. The loose aggregate surfacing was also blown away.

**Figure 4-83:**
This satellite dish was held down only with CMU. Note the displaced LPS at the corner (circled).

**Figure 4-84:**
This pre-engineered storage building contained the hospital supplies and maintenance shop.

### 4.3.4 NONSTRUCTURAL SYSTEMS AND EQUIPMENT

Nonstructural systems and equipment include all components that are not part of the structural system or building envelope. Exterior-mounted mechanical equipment (e.g., exhaust fans, HVAC units, relief air hoods, rooftop ductwork, and boiler stacks), electrical equipment (e.g., light fixtures and lightning protection systems), and communications equipment (e.g., antennae and satellite dishes) are often damaged during high winds. Damaged equipment can impair the operation of the facility, the equipment can detach and become wind-borne missiles, and water can enter the facility where equipment was displaced (see Figure 4-85). The most common problems typically relate to inadequate equipment anchorage, inadequate strength of the equipment itself, and corrosion.

Exterior-mounted equipment is especially vulnerable to hurricane-induced damage, and special attention should be paid to positioning and mounting of these components in hurricane-prone regions. Specific information pertaining to hospitals located in hurricane-prone regions is presented for each of the nonstructural component sections below.

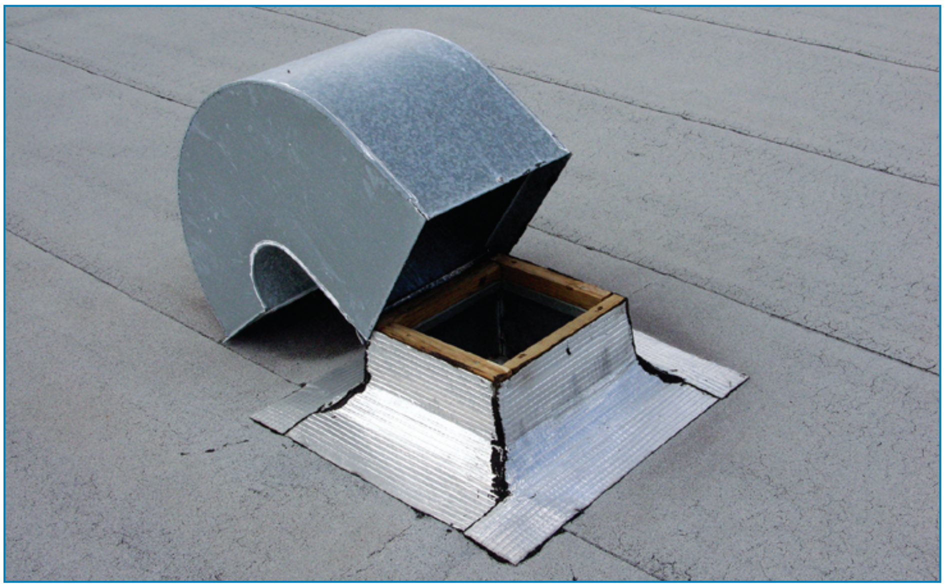


**Figure 4-85:**
This gooseneck was attached with only two small screws. A substantial amount of water was able to enter the building during Hurricane Francis. (Florida, 2004)

### 4.3.4.1 Exterior-Mounted Mechanical Equipment

This section discusses loads and attachment methods, as well as the problems of corrosion and water infiltration.

#### Loads and Attachment Methods[12]

Information on loads on rooftop equipment was first introduced in the 2002 edition of ASCE 7. For guidance on load calculations, see "*Calculating Wind Loads and Anchorage Requirements for Rooftop Equipment*" (ASHRAE, 2006). A minimum safety factor of 3 is recommended for hospitals. Loads and resistance should also be calculated for heavy pieces of equipment since the dead load of the equipment is often inadequate

12 Discussion is based on: *Attachment of Rooftop Equipment in High-Wind Regions* - Hurricane Katrina Recovery Advisory (May 2006, revised July 2006)

to resist the design wind load. The 30' x 10' x 8' 18,000-pound HVAC unit shown in Figure 4-86 was attached to its curb with 16 straps (one screw per strap). Although the wind speeds were estimated to be only 85 to 95 miles per hour (peak gust), the HVAC unit blew off the medical office building. The inset at Figure 4-86 shows the curb upon which the unit was attached. A substantial amount of water entered the building at the curb openings before the temporary tarp was placed.

Mechanical penetrations through the elevator penthouse roof and walls must possess adequate wind and water resistance to ensure continuity of elevator service (see Section 4.3.3.5). In addition to paying special attention to equipment attachment, air intakes and exhausts should be designed and constructed to prevent wind-driven water from entering the penthouse.

**Figure 4-86:**
Although this 18,000-pound HVAC unit was attached to its curb with 16 straps, it blew off during Hurricane Ivan. (Florida, 2004)

To anchor fans, small HVAC units, and relief air hoods, the minimum attachment schedule provided in Table 4-1 is recommended. The attachment of the curb to the roof deck also needs to be designed and constructed to resist the design loads. The cast-in-place concrete curb shown in Figure 4-87 was cold-cast over a concrete roof deck. Dowels were not installed between the deck and the curb, hence a weak connection occurred.

Figure 4-87:
The gooseneck on this hospital remained attached to the curb, but the curb detached from the deck. Typhoon Paka (Guam, 1997)

**Fan cowling attachment:** Fans are frequently blown off their curbs because they are poorly attached. When fans are well attached, the cowlings frequently blow off (see Figure 4-88). Blown off cowlings can tear roof membranes and break glazing. Unless the fan manufacturer specifically engineered the cowling attachment to resist the design wind load, cable tie-downs (see Figure 4-89) are recommended to avoid cowling blow-off. For fan cowlings less than 4 feet in diameter, $\frac{1}{2}$-inch diameter stainless steel cables are recommended. For larger cowlings, use $\frac{3}{16}$-inch diameter cables. When the basic wind speed is 120 mph or less, specify two cables. Where the basic wind speed is greater than 120 mph, specify four cables. To minimize leakage potential at the anchor point, it is recommended that the cables be adequately anchored to the equipment curb (rather than anchored to the roof deck). The attachment of the curb itself also needs to be designed and specified.

To avoid corrosion-induced failure (Figure 4-21), it is recommended that exterior-mounted mechanical, electrical, and communications equipment be made of nonferrous metals, stainless steel, or steel with minimum G-90 hot-dip galvanized coating for the equipment body, stands, anchors, and fasteners. When equipment with enhanced corrosion protection is not available, the designer should advise the building owner that periodic equipment maintenance and inspection is particularly important to avoid advanced corrosion and subsequent equipment damage during a windstorm.

Table 4-1: Number of #12 Screws for Base Case Attachment of Rooftop Equipment

| Case No | Curb Size and Equipment Type | Equipment Attachment | Fastener Factor for Each Side of Curb or Flange |
|---|---|---|---|
| 1 | 12″ x 12″ Curb with Gooseneck Relief Air Hood | Hood Screwed to Curb | 1.6 |
| 2 | 12″ x 12″ Gooseneck Relief Air Hood with Flange | Flange Screwed to 22 Gauge Steel Roof Deck | 2.8 |
| 3 | 12″ x 12″ Gooseneck Relief Air Hood with Flange | Flange Screwed to 15/32″ OSB Roof Deck | 2.9 |
| 4 | 24″ x 24″ Curb with Gooseneck Relief Air Hood | Hood Screwed to Curb | 4.6 |
| 5 | 24″ x 24″ Gooseneck Relief Air Hood with Flange | Flange Screwed to 22 Gauge Steel Roof Deck | 8.1 |
| 6 | 24″ x 24″ Gooseneck Relief Air Hood with Flange | Flange Screwed to 15/32″ OSB Roof Deck | 8.2 |
| 7 | 24″ x 24″ Curb with Exhaust Fan | Fan Screwed to Curb | 2.5 |
| 8 | 36″ x 36″ Curb with Exhaust Fan | Fan Screwed to Curb | 3.3 |
| 9 | 5′-9″ x 3′- 8″ Curb with 2′- 8″ high HVAC Unit | HVAC Unit Screwed to Curb | 4.5* |
| 10 | 5′-9 ″x 3′- 8″ Curb with 2′- 8″ high Relief Air Hood | Hood Screwed to Curb | 35.6* |

Notes to Table 4-1:

1. The loads are based on ASCE 7-05. The resistance includes equipment weight.
2. The Base Case for the tabulated numbers of #12 screws (or ¼ pan-head screws for flange-attachment) is a 90-mph basic wind speed, 1.15 importance factor, 30′ building height, Exposure C, using a safety factor of 3.
3. For other basic wind speeds, multiply the tabulated number of #12 screws by $\left(\frac{V_D^2}{90^2}\right)$ to determine the required number of #12 screws (or ¼ pan-head screws) required for the desired basic wind speed, $V_D$ (mph).
4. For other roof heights up to 200′, multiply the tabulated number of #12 screws by (1.00 + 0.003 [h - 30]) to determine the required number of #12 screws or ¼ pan-head screws for buildings between 30′ and 200′.

   Example A: 24″ x 24″ exhaust fan screwed to curb (table row 7), Base Case conditions (see Note 1): 2.5 screws per side; therefore, round up and specify 3 screws per side.

   Example B: 24″ x 24″ exhaust fan screwed to curb (table row 7), Base Case conditions, except 120 mph: $120^2$ x 1 ÷ $90^2$ = 1.78 x 2.5 screws per side = 4.44 screws per side; therefore, round down and specify 4 screws per side.

   Example C: 24″ x 24″ exhaust fan screwed to curb (table row 7), Base Case conditions, except 150′ roof height: 1.00 + 0.003 (150′ - 30′) = 1.00 + 0.36 = 1.36 x 2.5 screws per side = 3.4 screws per side; therefore, round down and specify 3 screws per side.

* This factor only applies to the long sides. At the short sides, use the fastener spacing used at the long sides.

Figure 4-88:
Cowlings blew off two of the three fans. Note also the loose lightning protection system conductors and missing walkway pad (red arrow). Hurricane Charley (Florida, 2004)

Figure 4-89:
Cables were attached to prevent the cowling from blowing off. Typhoon Paka (Guam, 1997)

**Ductwork:** To avoid wind and wind-borne debris damage to rooftop ductwork, it is recommended that ductwork not be installed on the roof (see Figures 4-16, 4-60, and 4-124). If ductwork is installed on the roof, it is recommended that the ducts' gauge and the method of attachment be able to resist the design wind loads.

**Condenser attachment:** In lieu of placing rooftop-mounted condensers on wood sleepers resting on the roof (see Figure 4-90), it is recommended that condensers be anchored to equipment stands. The attachment of the stand to the roof deck also needs to be designed to resist the design loads. In addition to anchoring the base of the condenser to the stand, two metal straps with two side-by-side #12 screws or bolts with proper end and edge distances at each strap end are recommended when the basic wind speed is greater than 90 mph (see Figure 4-91).

**Figure 4-90:** Sleeper-mounted condensers displaced by high winds. Hurricane Katrina (Mississippi, 2005)

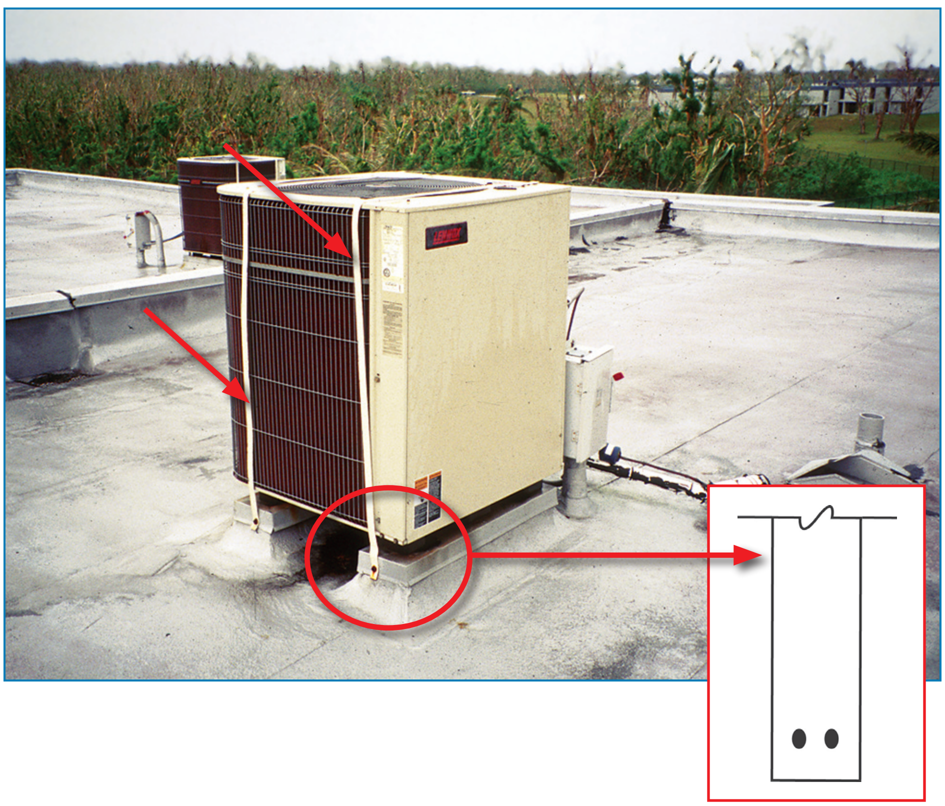


**Figure 4-91:** This condenser had supplemental attachment straps (see red arrows). Typhoon Paka (Guam, 1997)

Three publications pertaining to seismic restraint of equipment provide general information on fasteners and edge distances:

- *Installing Seismic Restraints for Mechanical Equipment* (FEMA 412, 2002)
- *Installing Seismic Restraints for Electrical Equipment* (FEMA 413, 2004)
- *Installing Seismic Restraints for Duct and Pipe* (FEMA 414, 2004)

**Vibration isolators:** If vibration isolators are used to mount equipment, only those able to resist design uplift loads should be specified and installed, or an alternative means to accommodate uplift resistance should be provided (see Figure 4-92).

**Figure 4-92:** Failure of vibration isolators that provided lateral resistance but no uplift resistance caused equipment damage. A damaged vibration isolator is shown in the inset. Hurricane Katrina (Mississippi, 2005)

**Boiler and exhaust stack attachment:** To avoid wind damage to boiler and exhaust stacks, wind loads on stacks should be calculated and guy-wires should be designed and constructed to resist the loads. Toppled stacks, as shown at the hospital in Figure 4-93, can allow water to enter the building at the stack penetration, damage the roof membrane, and become wind-borne debris. The designer should advise the building owner that guy-wires should be inspected annually to ensure they are taut.

**Figure 4-93:**
Three of the five stacks that did not have guy-wires were blown down. Hurricane Marilyn (U.S. Virgin Islands, 1995)

**Access panel attachment:** Equipment access panels frequently blow off. To minimize this, job-site modifications, such as attaching hasps and locking devices like carabiners, are recommended. The modification details need to be customized. Detailed design may be needed after the equipment has been delivered to the job site. Modification details should be approved by the equipment manufacturer.

**Equipment screens:** Screens around rooftop equipment are frequently blown away (see Figure 4-94). Screens should be designed to resist the wind load derived from ASCE 7. Since the effect of screens on equipment wind loads is unknown, the equipment attachment behind the screens should be designed to resist the design load.

**Figure 4-94:**
Equipment screen panels, such as these blown away at a hospital, can break glazing, puncture roof membranes, and cause injury. Hurricane Ivan (Florida, 2004)

### Water Infiltration

During high winds, wind-driven rain can be driven through air intakes and exhausts unless special measures are taken. Louvers should be designed and constructed to prevent leakage between the louver and wall. The louver itself should be designed to avoid water being driven past the louver. However, it is difficult to prevent infiltration during very high winds. Designing sumps with drains that will intercept water driving past louvers or air intakes should be considered. ASHRAE 62.1 (2004) provides some information on rain and snow intrusion. The *Standard 62.1 User's Manual* provides additional information, including examples and illustrations of various designs.

## 4.3.4.2 Nonstructural Systems and Mechanical Equipment in Hurricane-Prone Regions

**Elevators:** Where interruption of elevator service would significantly disrupt facility operations, it is recommended that elevators be placed in separate locations within the building and be served by separate elevator penthouses. This is recommended, irrespective of the elevator penthouse enhancements recommended in Sections 4.3.3.5, 4.3.3.7, and 4.3.4.1, because of the greater likelihood that at least one of the elevators will remain operational and therefore allow the facility to function as intended, as discussed in Section 4.2.1.3.

**Mechanical Penthouses:** By placing equipment in mechanical penthouses rather than leaving them exposed on the roof, equipment can be shielded from high-wind loads and wind-borne debris. Although screens (such as shown in Figure 4-94) could be designed and constructed to protect equipment from horizontally-flying debris, they are not effective in protecting equipment from missiles that have an angular trajectory. It is therefore recommended that mechanical equipment be placed inside mechanical penthouses. The penthouse itself should be designed and constructed in accordance with the recommendations given in Sections 4.3.2.1, 4.3.3.6, and 4.3.3.8.

## 4.3.4.3 Exterior-Mounted Electrical and Communications Equipment

Damage to exterior-mounted electrical equipment is infrequent, mostly because of its small size (e.g., disconnect switches). Exceptions include communication towers, surveillance cameras, electrical service masts, satellite dishes, and lightning protection systems. The damage is typically caused by inadequate mounting as a result of failure to perform wind load calculations and anchorage design. Damage is also sometimes caused by corrosion (see Figure 4-21 and text box in Section 4.3.4.1 regarding corrosion).

**Communication towers and poles:** ANSI/C2 provides guidance for determining wind loads on power distribution and transmission poles and towers. AASHTO LTS-4-M (amended by LTS-4-12 2001 and 2003, respectively) provides guidance for determining wind loads on light fixture poles (standards).

Both ASCE 7 and ANSI/TIA-222-G contain wind load provisions for communication towers (structures). The IBC allows the use of either approach. The ASCE wind load provisions are generally consistent with those contained in ANSI/TIA-222-G. ASCE 7, however, contains provisions for dynamically sensitive towers that are not present in the ANSI/TIA standard. ANSI/TIA classifies towers according to their use (Class I, Class II, and Class III). This manual recommends that towers (including antennae) that are mounted on, located near, or serve hospitals be designed as Class III structures.

Collapse of both large and small communication towers at hospitals is quite common during high-wind events (see Figures 4-15 and 4-95). These failures often result in complete loss of communication capabilities. In addition to the disruption of communications, collapsed towers can puncture roof membranes and allow water leakage into the hospital, unless the roof system incorporated a secondary membrane (as discussed in Section 4.3.3.8). At the tower shown in Figure 4-95, the anchor bolts were pulled out of the deck, which resulted in a progressive peeling of the fully adhered single-ply roof membrane. Tower collapse can also injure or kill people.

**Figure 4-95:**
The collapse of the antenna tower caused progressive peeling of the roof membrane. Also note that the exhaust fan blew off the curb, but the high parapet kept it from blowing off the roof. Hurricane Andrew (Florida, 1992)

See Sections 4.3.1.1 and 4.3.1.5 regarding site considerations for light fixture poles, power poles, and electrical and communications towers.

**Electrical service masts:** Service mast failure is typically caused by collapse of overhead power lines, which can be avoided by using underground service. Where overhead service is provided, it is recommended that the service mast not penetrate the roof. Otherwise, a downed service line could pull on the mast and rupture the roof membrane.

**Satellite dishes:** For the satellite dish shown in Figure 4-96, the dish mast was anchored to a large metal pan that rested on the roof membrane. CMU was placed on the pan to provide overturning resistance. This anchorage method should only be used where calculations demonstrate that it provides sufficient resistance. In this case the wind approached the satellite dish in such a way that it experienced very little wind pressure. In hurricane-prone regions, use of this anchorage method is not recommended (see Figures 4-83 and 4-97).

**Figure 4-96:** Common anchoring method for satellite dish. Hurricane Ivan (Florida, 2004)

**Figure 4-97:** A satellite dish anchored similarly to that shown in Figure 4-96 was blown off this five-story building. Hurricane Charley (Florida, 2004)

**Lightning protection systems:** For attachment of building lightning protection systems higher than 100 feet above grade, and for buildings located where the basic wind speed is in excess of 90 mph, see the following section on attaching LPS in hurricane-prone regions.

### 4.3.4.4 Lightning Protection Systems (LPS) in Hurricane-Prone Regions

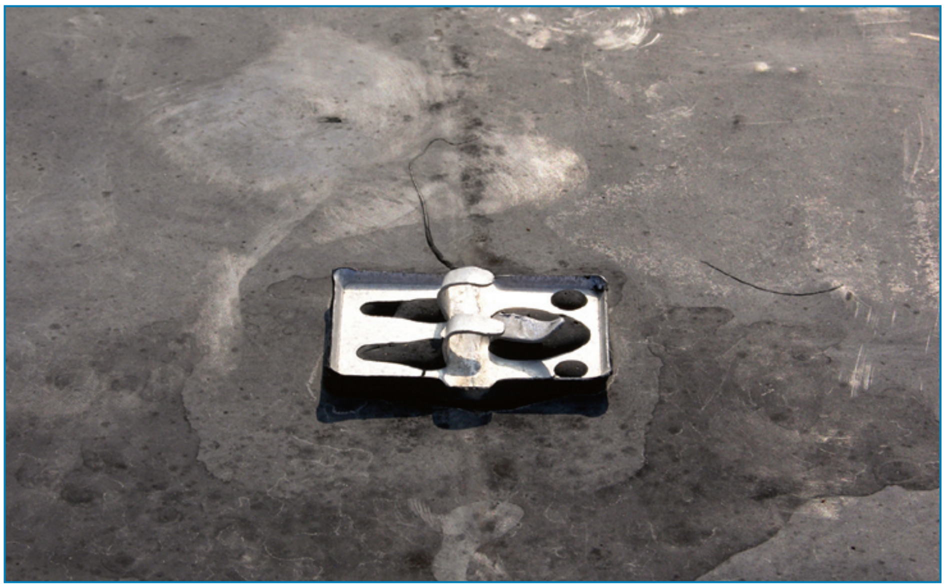
Lightning protection systems frequently become disconnected from rooftops during hurricanes. Displaced LPS components can puncture and tear roof coverings, thus allowing water to leak into buildings (see Figures 4-98 and 4-99). Prolonged and repeated slashing of the roof membrane by loose conductors ("cables") and puncturing by air terminals ("lightning rods") can result in lifting and peeling of the membrane. Also, when displaced, the LPS is no longer capable of providing lightning protection in the vicinity of the displaced conductors and air terminals.

**Figure 4-98:** An air terminal debonded from the hospital's roof. Displaced air terminals can puncture tough membranes, such as this modified bitumen membrane. Hurricane Ivan (Florida, 2004)

**Figure 4-99:** View of an end of a conductor at a hospital that became disconnected. Hurricane Katrina (Mississippi, 2005)

Lightning protection standards such as NFPA 780 and UL 96A provide inadequate guidance for attaching LPS to rooftops in hurricane-prone regions, as are those recommendations typically provided by LPS and roofing material manufacturers. LPS conductors are typically attached to the roof at 3-foot intervals. The conductors are flexible, and when they are exposed to high winds, the conductors exert dynamic loads on the conductor connectors ("clips"). Guidance for calculating the dynamic loads does not exist. LPS conductor connectors typically have prongs to anchor the conductor. When the connector is well-attached to the roof surface, during high winds the conductor frequently bends back the malleable connector prongs (see Figure 4-100). Conductor connectors have also debonded from roof surfaces during high winds. Based on observations after Hurricane Katrina and other hurricanes, it is apparent that pronged conductor connectors typically have not provided reliable attachment.

**Figure 4-100:**
The conductor deformed the prongs under wind pressure, and pulled away from the connector. Hurricane Katrina (Mississippi, 2005)



To enhance the wind performance of LPS, the following are recommended[13]:

**Parapet attachment:** When the parapet is 12-inches high or greater, it is recommended that the air terminal base plates and conductor connectors be mechanically attached with #12 screws that have minimum 1¼-inch embedment into the inside face of the parapet nailer and are properly sealed for watertight protection. Instead of conductor connectors that have prongs, it is recommended that mechanically attached looped connectors be installed (see Figure 4-101).

13 Discussion is based on *Rooftop Attachment of Lightning Protection Systems in High-Wind Regions*—Hurricane Katrina Recovery Advisory (May 2006, Revised July 2006).

**Figure 4-101:** This conductor was attached to the coping with a looped connector. Hurricane Katrina (Mississippi, 2005)

**Attachment to built-up, modified bitumen, and single-ply membranes:** For built-up and modified bitumen membranes, attach the air terminal base plates with asphalt roof cement. For single-ply membranes, attach the air terminal base plates with pourable sealer (of the type recommended by the membrane manufacturer).

In lieu of attaching conductors with conductor connectors, it is recommended that conductors be attached with strips of membrane installed by the roofing contractor. For built-up and modified bitumen membranes, use strips of modified bitumen cap sheet, approximately 9 inches wide at a minimum. If strips are torch-applied, avoid overheating the conductors. For single-ply membranes, use self-adhering flashing strips, approximately 9 inches wide at a minimum. Start the strips approximately 3 inches from either side of the air terminal base plates. Use strips that are approximately 3 feet long, separated by a gap of approximately 3 inches (see Figure 4-102).

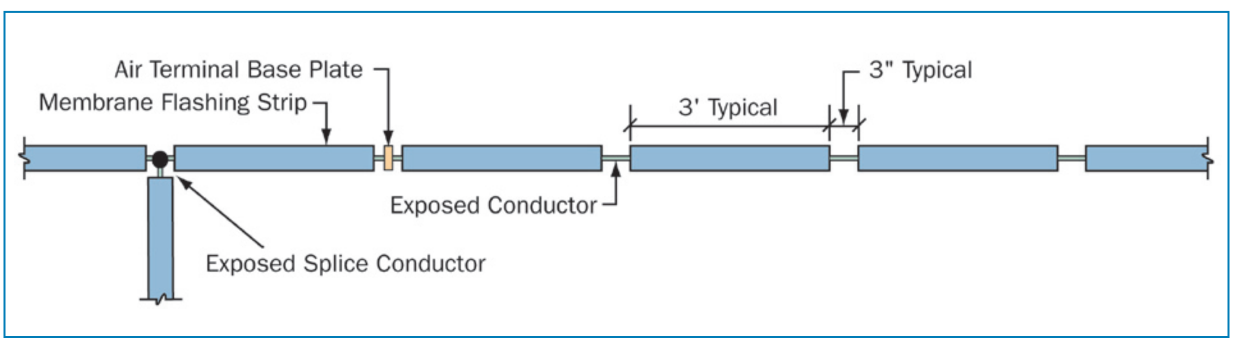



**Figure 4-102:** Plan showing conductor attachment

As an option to securing the conductors with stripping plies, conductor connectors that do not rely on prongs could be used (such as the one shown in Figure 4-103). However, the magnitude of the dynamic loads induced by the conductor is unknown, and there is a lack of data on the resistance provided by adhesively-attached connectors. For this reason, attachment with stripping plies is the preferred option, because the plies shield the conductor from the wind. If adhesive-applied conductor connectors are used, it is recommended that they be spaced more closely than the 3-foot spacing required by NFPA 780 and UL 96A. Depending on wind loads, a spacing of 6 to 12 inches on center may be needed in the corner regions of the roof, with a spacing of 12 to 18 inches on center at roof perimeters (see ASCE 7 for the size of corner regions).

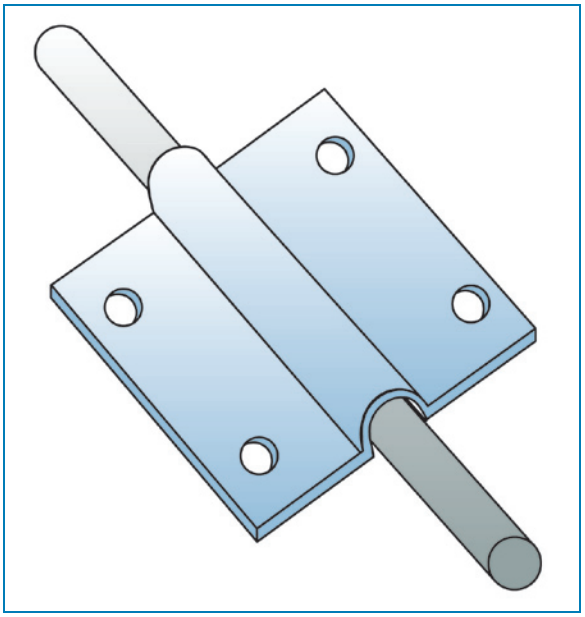


**Figure 4-103:**
Adhesively attached conductor connector that does not use prongs

**Mechanically attached single-ply membranes:** It is recommended that conductors be placed parallel to, and within 8 inches of, membrane fastener rows. Where the conductor falls between or is perpendicular to membrane fastener rows, install an additional row of membrane fasteners where the conductor will be located, and install a membrane cover-strip over the membrane fasteners. Place the conductor over the cover-strip and secure the conductor as recommended above.

By following the above recommendations, additional rows of membrane fasteners (beyond those needed to attach the membrane) may be needed to accommodate the layout of the conductors. The additional membrane fasteners and cover-strip should be coordinated with, and installed by, the roofing contractor.

**Standing seam metal roofs:** It is recommended that pre-manufactured, mechanically attached clips that are commonly used to attach various items to roof panels be used. After anchoring the clips to the panel ribs, the air terminal base plates and conductor connectors are anchored to the panel clips. In lieu of conductor connectors that have prongs, it is recommended that mechanically attached looped connectors be installed (see Figure 4-101).

It is recommended that the building designer advise the building owner to have the LPS inspected each spring, to verify that connectors are still attached to the roof surface, that they still engage the conductors, and that the splice connectors are still secure. Inspections are also recommended after high-wind events.

**Conductor splice connectors:** In lieu of pronged splice connectors (see Figure 4-104), bolted splice connectors are recommended because they provide a more reliable connection (see Figure 4-105). It is recommended that strips of flashing membrane (as recommended above) be placed approximately 3 inches from either side of the splice connector to minimize conductor movement and to avoid the possibility of the conductors becoming disconnected. To allow for observation during maintenance inspections, do not cover the connectors.

Figure 4-104:
If conductors detach from the roof, they are likely to pull out from pronged splice connectors. Hurricane Charley (Florida, 2004)

Figure 4-105:
Bolted splice connectors are recommended to prevent free ends of connectors from being whipped around by wind. Hurricane Katrina (Mississippi, 2005)

### 4.3.4.5 The Case of Martin Memorial Medical Center, Stuart, Florida

The case of Martin Memorial Hospital illustrates the importance of elevator penthouse envelopes. Martin Memorial Medical Center is a 244-bed facility located on the south bank of the St. Lucie River in Stuart, Florida. The original hospital building, opened in 1939, is still in use but not for patient care. Currently the main hospital building is the six-story North Tower constructed in the early 1970s. MOBs and a cancer treatment facility are also located on the hospital campus. In 2004 the facility was struck by Hurricane Frances, and about 3 weeks later by Hurricane Jeanne. The estimated peak gust wind speed at this site during Hurricane Frances was 100 mph.[14] The design wind speed in the 2005 edition of ASCE 7 for this location is 140 mph.

The hospital sustained damage to the elevator penthouse, roof covering, and roof-mounted equipment. Many of the metal panels on the elevator penthouse of the North Tower that were blown off during Hurricane Frances (Figure 4-106) tore the roof membrane on the tower roof as well as on lower roofs. Mechanical equipment was damaged on the tower roof (Figure 4-107) and on lower roofs. The LPS was displaced on the tower roof (Figure 4-108) and on lower roofs. Unlike the windows on the first floor that were protected with shutters, the upper-level windows were not protected. However, none of them were broken, although a significant amount of water leaked through many of these windows. The second hurricane (Jeanne) caused additional water infiltration and interrupted reconstruction work.

**Figure 4-106:** View of the reconstruction of the damaged walls at the elevator penthouse

14 The 100 mph speed was estimated for exposure C.

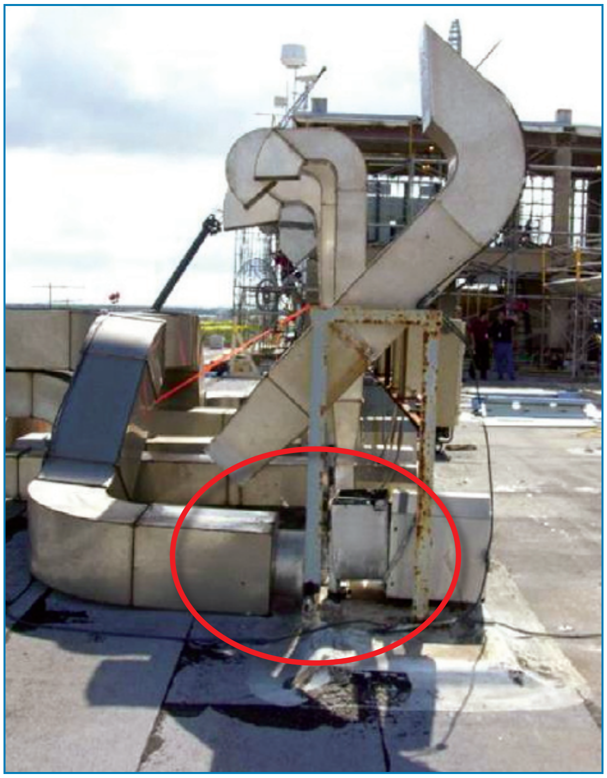


Figure 4-107:
Damaged HVAC equipment. Work is underway on the elevator penthouse beyond.

Figure 4-108:
Displaced LPS

Loss of the elevator penthouse panels allowed water infiltration into the elevator equipment room, which destroyed the control equipment. Water also leaked into the nursing floors, which made it necessary to evacuate the patients. Because of significant interior water damage and lack of vertical transportation, many patients had to be evacuated by helicopter.

As dramatically illustrated at this hospital, water infiltration and the lack of elevator service can take portions of the hospital offline for several weeks. Rather than simply replace the elevator penthouse walls, an engineer was retained to design a more wind-resistant wall covering system. The new design for the elevator penthouse wall system was developed and new elevator control equipment was installed, bringing the 5th floor back online about 4 weeks after the first hurricane struck. The remaining floors (2, 3, 4, and 6) were brought back online at a rate of about one floor every 2 weeks after the 5th floor was reopened. It cost $3,733,233 to repair the North Tower. In addition to this expenditure, the hospital lost a significant amount of patient revenue.

Electrical service was interrupted for 36 hours (generators were used during that time), though there was no disruption of site access or water, sewer, and communications services. The hospital had an existing contingency plan, which was helpful during the response to these hurricanes. For instance, the hospital had contractors on site the day after the hurricane struck to perform emergency repairs; some of these contractors were under a pre-arranged contract with the hospital. The contingency plan was updated and modified based on experiences with these two hurricanes.

## 4.3.5 MUNICIPAL UTILITIES IN HURRICANE-PRONE REGIONS

Hurricanes typically disrupt municipal electrical service, and often they disrupt telephone (both cellular and landline), water, and sewer services. These disruptions may last from several days to several weeks. Electrical power disruptions can be caused by damage to power generation stations and by damaged lines, such as major transmission lines and secondary feeders. Water disruptions can be caused by damage to water treatment or well facilities, lack of power for pumps or treatment facilities, or by broken water lines caused by uprooted trees. Sewer disruptions can be caused by damage to treatment facilities, lack of power for treatment facilities or lift stations, or broken sewer lines. Phone disruptions can be caused by damage at switching facilities and collapse of towers. Hospitals should be designed to prevent the disruption of services arising from prolonged loss of municipal services.

### 4.3.5.1 Electrical Power

It is recommended that buildings on hospital campuses that will be occupied during a hurricane, or will be needed within the first few weeks afterwards, be equipped with one or more emergency generators. In addition to providing emergency generators, it is recommended that one or more additional standby generators be considered, because continued availability of electrical power is vital. The purpose of providing the standby generators is to power those circuits that are not powered by the emergency generators. With both emergency and standby generators, the entire facility will be completely backed up. It is recommended that the emergency generator and standby generator systems be electrically connected via manual transfer switches to allow for interconnectivity in the event of emergency generator failure. The standby circuits can be disconnected from the standby generators, and the emergency circuits can be manually added. The emergency generators should be rated for prime power (continuous operation).

Running generators for extended time periods frequently results in equipment failure. Thus, provisions for back-up generation capacity are important, because the municipal power system may be out of service for many days or even weeks. Therefore, it is recommended that an exterior box for single pole cable cam locking connectors be provided, so that a portable generator can be connected to the facility. With a cam locking box, if one or more of the emergency or standby generators malfunction, a portable generator can be brought to the facility and quickly connected. Back-up portable generators should be viewed as a third source of power (i.e., they should not replace standby generators), because it may take several days to get a back-up portable generator to the site.

Generators should be placed inside wind-borne debris resistant buildings (see recommendations in Sections 4.3.2.1, 4.3.3.2, 4.3.3.6 and 4.3.3.8) so that they are not susceptible to damage from debris or tree fall. Locating generators outdoors or inside weak enclosures (see Figure 4-138) is not recommended.

It is recommended that wall louvers for generators be capable of resisting the test Missile E load specified in ASTM E 1996. Alternatively, wall louvers can be protected with a debris-resistant screen wall so that wind-borne debris is unable to penetrate the louvers and damage the generators. If a screen wall is used, it should be designed to allow adequate air flow to the generator in order to avoid overheating the generator.

It is recommended that sufficient onsite fuel storage be provided to allow all of the facility's emergency and standby generators to operate at full capacity for a minimum of 96 hours (4 days).[15] If at any time it appears that refueling won't occur within 96 hours, provision should be made to shut off part or all the standby circuits in order to provide longer operation of the emergency circuits. For remote facilities or situations where it is believed that refueling may not occur within 96 hours, the onsite fuel storage capacity should be increased as deemed appropriate. It is recommended that fuel storage tanks, piping, and pumps be placed inside wind-borne debris resistant buildings, or underground. If the site is susceptible to flooding, refer to Chapter 3 recommendations.

> It is recommended that a minimum of 96 hours (4 days) of onsite fuel storage be provided for boilers. Storage tanks, piping, and pumps should be located within wind-borne debris resistant buildings or be placed underground (if site is susceptible to flooding, refer to Chapter 3).

### 4.3.5.2 Water Service

It is recommended that hospitals be provided with an independent water supply — a well or onsite water storage. If water is needed for cooling towers, the independent water supply should be sized to accommodate the system. It is recommended that the well or onsite storage be capable of providing an adequate water supply for fire sprinklers. Alternatively, it

15 The 96-hour fuel supply is based in part on the Department of Veterans Affairs criteria.

is recommended that the building designer should advise the building owner to implement a continual fire-watch and provide additional fire extinguishers until the municipal water service is restored. It is recommended that the well or onsite water storage be capable of providing a minimum of 100 gallons of potable water per day per patient bed for four days (the 100 gallons includes water for cooling towers).[16]

It is recommended that onsite storage of medical gases be sized to provide a minimum of 96 hours (4 days) of service.

It is recommended that pumps for wells or onsite storage be connected to an emergency power circuit, that a valve be provided on the municipal service line, and that onsite water treatment capability be provided where appropriate.

#### 4.3.5.3 Sewer Service

It is recommended that hospitals be provided with an alternative means of waste disposal, such as a temporary storage tank that can be pumped out by a local contractor. It is also recommended that back-flow preventors be provided.

### 4.3.6 POST-DESIGN CONSIDERATIONS IN HURRICANE-PRONE REGIONS

In addition to adequate design, proper attention must be given to construction, post-occupancy inspections, and maintenance.

#### 4.3.6.1 Construction Contract Administration

It is important for owners of hospitals in hurricane-prone regions to obtain the services of a professional contractor who will execute the work described in the contract documents in a diligent and technically proficient manner. The frequency of field observations and extent of special inspections and testing should be greater than those employed on hospitals that are not in hurricane-prone regions.

#### 4.3.6.2 Periodic Inspections, Maintenance, and Repair

The recommendations given in Section 4.3.1.4 for post-occupancy and post-storm inspections, maintenance, and repair are crucial for hospitals in hurricane-prone regions. Failure of a building component that was not maintained properly, repaired, or replaced can present a considerable risk of injury or death to occupants, and the continued operation of the facility can be jeopardized.

16 This recommendation is based on the Department of Veterans Affairs criteria.

# 4.4 REMEDIAL WORK ON EXISTING FACILITIES

Many existing hospitals need to strengthen their structural or building envelope components. The reasons for this are the deterioration that has occurred over time, or inadequate facility strength to resist current design level winds. It is recommended that building owners have a vulnerability assessment performed by a qualified architectural and engineering team. A vulnerability assessment should be performed for all facilities older than 5 years. An assessment is recommended for all facilities located in areas where the basic wind speed is greater than 90 mph (even if the facility is younger than 5 years—see Figure 4-109). It is particularly important to perform vulnerability assessments on hospitals located in hurricane-prone and tornado-prone regions.

Components that typically make buildings constructed before the early 1990s vulnerable to high winds are weak non-load-bearing masonry walls, poorly connected precast concrete panels, long-span roof structures with limited uplift resistance, inadequately connected roof decks, weak glass curtain walls, building envelope, and exterior-mounted equipment. Although the technical solutions to these problems are not difficult, the cost of the remedial work is typically quite high. If funds are not available for strengthening or replacement, it is important to minimize the risk of injury and death by evacuating areas adjacent to weak non-load-bearing walls, weak glass curtain walls, and areas below long-span roof structures when winds above 60 mph are forecast.

Although it is unlikely, a hospital may occupy a building that was originally intended for another use. Buildings that were not designed for a critical occupancy were likely designed with a 1.0 rather than a 1.15 importance factor, and hence are not as wind-resistant as needed. It is particularly important to perform a vulnerability assessment if a hospital is located in a building not originally designed for a critical occupancy, especially if the hospital is located in a hurricane- or tornado-prone region.

As a result of building code changes and heightened awareness, some of the common building vulnerabilities have generally been eliminated for facilities constructed in the mid-1990s or later. Components that typically remain vulnerable to high winds are the building envelope and exterior-mounted mechanical, electrical, and communications equipment. Many failures can be averted by identifying weaknesses and correcting them.

**Figure 4-109:**
The roof on this 5-year old hospital blew off. Water leaked into the patient floor below. The floor was taken out of service for more than a month. Hurricane Katrina (Mississippi, 2005)

By performing a vulnerability assessment, items that need to be strengthened or replaced can be identified and prioritized. A proactive approach in mitigating weaknesses can save significant sums of money and decrease disruption or total breakdown in hospital operations after a storm. For example, a vulnerability assessment on a hospital such as that shown in Figure 4-110 may identify weakness of the roof membrane and/or rooftop equipment. Replacing weak components before a hurricane is much cheaper than replacing them and repairing consequential damages after a storm, and proactive work avoids the loss of use while repairs are made.

> Before beginning remedial work, it is necessary to understand all significant aspects of the vulnerability of a hospital with respect to wind and wind-driven rain. If funds are not available to correct all identified deficiencies, the work should be systematically prioritized so that the items of greatest need are first corrected. Mitigation efforts can be very ineffective if they do not address all items that are likely to fail.

**Figure 4-110:**
The roof membrane and some of the rooftop equipment blew off. Although the deck was cast-in-place concrete, water leaked into the patient floor below. Hurricane Charley (Florida, 2004)

A comprehensive guide for remedial work on existing facilities is beyond the scope of this manual. However, the following are examples of mitigation measures that are often applicable.

### 4.4.1 STRUCTURAL SYSTEMS

As discussed in Section 4.1.4.1, roof decks on many facilities designed prior to the 1982 edition of the SBC and UBC and the 1987 edition of the NBC are very susceptible to failure. Poorly attached decks that are not upgraded are susceptible to blow-off, as shown in Figures 4-111 and 4-132. Decks constructed of cementitious wood-fiber, gypsum, and lightweight insulating concrete over form boards were commonly used on buildings built in the 1950s and 1960s. In that era, these types of decks, as well as precast concrete decks, typically had very limited uplift resistance due to weak connections to the support structure. Steel deck attachment is frequently not adequate because of an inadequate number of welds, or welds of poor quality. Older buildings with overhangs are particularly susceptible to blow-off, as shown in Figure 4-112, because older codes provided inadequate uplift criteria.

Figure 4-111:
The built-up roof blew off after one of the cementitious wood-fiber deck panels detached from the joists. Hurricane Katrina (Mississippi, 2005)

Figure 4-112:
The cementitious wood-fiber deck panels detached from the joists along the overhangs and caused the built-up membranes to lift and peel. Hurricane Katrina (Mississippi, 2005)

A vulnerability assessment of the roof deck should include evaluating the existing deck attachment, spot checking the structural integrity of the deck (including the underside, if possible), and evaluating the integrity of the beams/joists. If the deck attachment is significantly overstressed under current design wind conditions or the deck integrity is compromised, the deck should be replaced or strengthened as needed. The evaluation should be conducted by an investigator experienced with the type of deck used on the building.

If a low-slope roof is converted to a steep-slope roof, the new support structure should be engineered and constructed to resist the wind loads and avoid the kind of damage shown in Figure 4-113.

Figure 4-113: The steel truss superstructure installed as part of a steep-slope conversion blew away because of inadequate attachment. Hurricane Marilyn (U.S. Virgin Islands, 1995)

## 4.4.2 BUILDING ENVELOPE

The following recommendations apply to building envelope components of existing hospitals.

### 4.4.2.1 Sectional and Rolling Doors

Sectional and rolling doors (e.g., at hospital loading docks and ambulance garages), installed in older buildings before attention was given to the wind resistance of these elements, are very susceptible to being blown away. Although weak doors can be retrofitted, it is difficult to ensure that the door, door tracks, and connections between the door and tracks are sufficient. It is therefore recommended that weak doors and tracks be replaced with new assemblies that have been tested to meet the factored design wind loads. As part of the replacement work, nailers between the tracks and building structure should either be replaced, or their attachment should be strengthened.

If a facility has more than one sectional or rolling door, all doors should be replaced, rather than just replacing one of the doors. The building shown in Figure 4-114 had six sectional doors. One door had been replaced before a hurricane. It performed very well, but three of the older doors were blown away and two of the older doors remained in place but had some wind damage.

Figure 4-114:
The new door in the center performed very well, but the older doors on either side of it were blown away. Hurricane Charley (Florida, 2004)

### 4.4.2.2 Windows and Skylights

Windows in older facilities may possess inadequate resistance to wind pressure. Window failures are typically caused by wind-borne debris, however, glazing or window frames may fail as a result of wind pressure (see Figure 4-115). Failure can be caused by inadequate resistance of the glazing, inadequate anchorage of the glazing to the frame, failure of the frame itself, or inadequate attachment of the frame to the wall. For older windows that are too weak to resist the current design pressures, window assembly replacement is recommended. Some older window assemblies have sufficient strength to resist the design pressure, but are inadequate to resist wind-driven rain. If the lack of water resistance is due to worn glazing gaskets or sealants, replacing the gaskets or sealant may be viable. In other situations, replacing the existing assemblies with new, higher-performance assemblies may be necessary.

It is recommended that all non-impact-resistant, exterior glazing located in hurricane-prone regions (with a basic wind speed of 100 mph or greater) be replaced with impact-resistant glazing or be protected with shutters, as discussed in Section 4.3.3.4. Shutters are typically a more economical approach for existing facilities. There are a variety of shutter types, all illustrated by Figures 4-116 to 4-118. Accordion shutters are permanently attached to the wall (Figure 4-116). When a hurricane is forecast, the shutters are pulled together and latched into place. Panel shutters (Figure 4-117) are made of metal or polycarbonate. When a hurricane is forecast, the shutters are taken from storage and inserted into metal tracks that are permanently mounted to the wall above and below the window frame. The panels are locked into the frame with wing nuts or clips. Track designs that have permanently mounted studs for the nuts have been shown to be more reliable than track designs using studs that slide into the track. A disadvantage of panel shutters is the need for storage space. Roll-down shutters (Figure 4-118) can be motorized or pulled down manually. Figure 4-118 illustrates the benefits of shuttering. Two of the unprotected window units experienced glass breakage and the third window unit blew in.

Deploying accordion or panel shutters a few stories above grade is expensive. Although motorized shutters have greater initial cost, their operational cost should be lower. Other options for providing missile protection on upper levels include replacing the existing assemblies with laminated glass assemblies, or installing permanent impact resistant screens. Engineered films are also available for application to the interior of the glass. The film needs to be anchored to the frame, and the frame needs to be adequately anchored to the wall. The film degrades over time and requires replacement (approximately every decade). Use of laminated glass or shutters is recommended in lieu of engineered films.

**Figure 4-115:**
Wind pressure caused the window frames on the upper floor to fail (red arrow). Hurricane Katrina (Mississippi, 2005)

Figure 4-116:
This building has accordion shutters. Hurricane Ivan (Florida, 2004)

Figure 4-117:
A metal panel shutter. Hurricane Georges (Puerto Rico, 1998)

Figure 4-118:
The lower window assembly was protected with a motorized shutter. Hurricane Ivan (Florida, 2004)

### 4.4.2.3 Roof Coverings

For roofs with weak metal edge flashing or coping attachment, face-attachment of the edge flashing/coping (as shown in Figure 4-67) is a cost-effective approach to greatly improve the wind-resistance of the roof system.

The vulnerability assessment of roofs ballasted with aggregate, pavers, or cementitious-coated insulation boards, should determine whether the ballast complies with ASNI/SPRI RP-4. Corrective action is recommended for non-compliant roof coverings. It is recommended that roof coverings with aggregate surfacing, lightweight pavers, or cementitious-coated insulation boards on buildings located in hurricane-prone regions be replaced to avoid blow-off (Figures 4-5, 4-46, and 4-47).

When planning the replacement of a roof covering, it is recommended that all existing roof covering be removed down to the deck rather than simply re-covering the roof. Tearing off the covering provides an opportunity to evaluate the structural integrity of the deck and correct deck attachment and other problems. For example, if a roof deck was deteriorated due to roof leakage (see Figure 4-119), the deterioration would likely not be identified if the roof was simply re-covered. By tearing off down to the deck, deteriorated decking like that shown in Figure 4-119 can be found and replaced. In addition, it is recommended that the attachment of the wood nailers at the top of parapets and roof edges be evaluated and strengthened where needed, to avoid blow-off and progressive lifting and peeling of the new roof membrane (see Figure 4-126).

**Figure 4-119:**
The built-up roof was blown off after a few of the rotted wood planks detached from the joists. Hurricane Katrina (Mississippi, 2005)

If the roof has a parapet, it is recommended that the inside of the parapet be properly prepared to receive the new base flashing. In many instances, it is prudent to re-skin the parapet with sheathing to provide a suitable substrate. Base flashing should not be applied directly to brick parapets because they have irregular surfaces that inhibit good bonding of the base flashing to the brick (see Figure 4-120). Also, if moisture drives into the wall from the exterior side of the parapet with base flashing attached directly to brick, the base flashing can inhibit drying of the wall. Therefore, rather than totally sealing the parapet with membrane base flashing, the upper portion of the brick can be protected by metal panels (as shown in Figure 4-79), which permit drying of the brick.

If the parapet is constructed of masonry, it is recommended that its wind resistance be evaluated and strengthened if found to be inadequate. The masonry parapet shown in Figure 4-139 fell onto the roof. Had it fallen in the other direction, it would have blocked the entry and would have had the potential to cause injury.

**Figure 4-120:** Failed base flashing adhered directly to the brick parapet. Hurricane Katrina (Louisiana, 2005)

### 4.4.3 EXTERIOR-MOUNTED EQUIPMENT

Exterior-mounted equipment on existing hospitals should be carefully examined and evaluated.

#### 4.4.3.1 Antenna (Communications Mast)

Antenna collapse is very common. Besides loss of communications, collapsed masts can puncture roof membranes or cause other building damage as shown in Figure 4-121. This case also demonstrates the benefits of a high parapet. Although the roof still experienced high winds that blew off this penthouse door, the parapet prevented the door from blowing off the roof (red arrow in Figure 4-121).

In hurricane-prone regions, it is recommended that antennae strength be evaluated as part of the vulnerability assessment. Chapter 15 of ANSI/TIA-222-G provides guidance on the structural evaluation of existing towers. Appendix J of that standard contains checklists for maintenance and condition assessments. Additional bracing, guy-wires, or tower strengthening or replacement may be needed.

> Fastening rooftop equipment to curbs, as discussed in Section 4.3.4.1, is a cost-effective approach to minimize wind-induced problems.

Figure 4-121:
The antenna at this hospital collapsed and was whipped back and forth across the roof membrane. Hurricane Andrew (Florida, 1992)

### 4.4.3.2 Lightning Protection Systems

Adhesively attached conductor connectors and pronged splice connectors typically have not provided reliable attachment during hurricanes. To provide more reliable attachment for LPS located in hurricane-prone regions where the basic wind speed is 100 mph or greater, or on hospitals more than 100 feet above grade, it is recommended that attachment modifications based on the guidance given in Section 4.3.4.4 be used.

## 4.4.4 THE CASE OF BAPTIST HOSPITAL, PENSACOLA, FLORIDA

The case of Baptist Hospital illustrates the challenges faced by older facilities. Baptist Hospital is a 492-bed tertiary care hospital located in downtown Pensacola on West Moreno St. approximately 2 miles north of Pensacola Bay. This hospital campus, which dates back to the 1950s, includes the hospital itself, a psychiatric hospital, and MOBs.

This facility was also struck by Hurricane Ivan. The estimated wind speed and design wind speed at this hospital are the same as the case study presented in Section 4.2.1.3. Figure 4-122 shows the site plan and Figure 4-123 is a general view from the northwest (looking southeast).

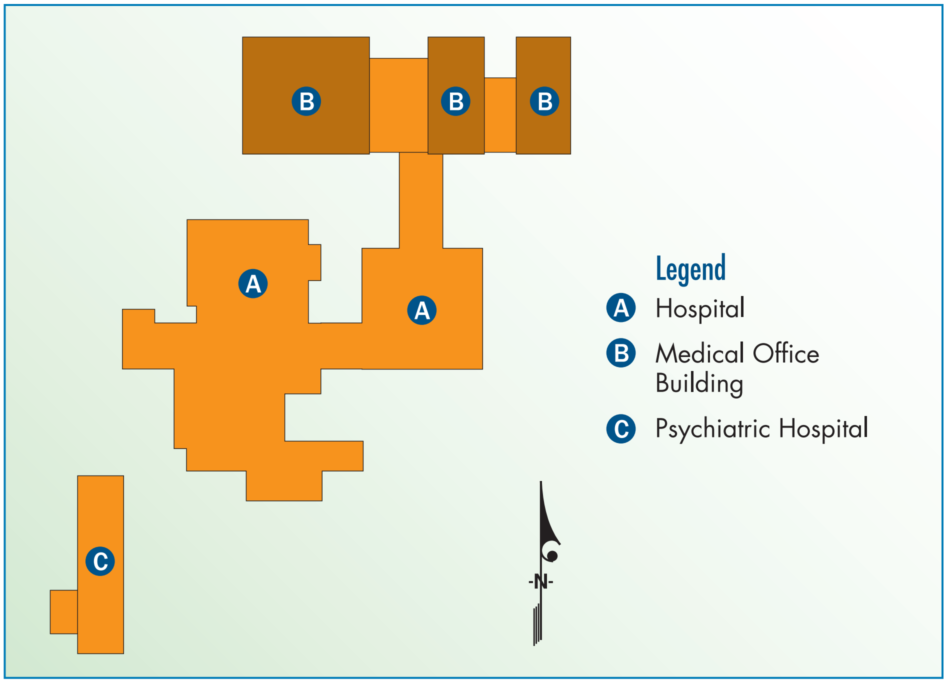



**Figure 4-122:** Site plan

**Figure 4-123:** General view

### Damage

Water entered the hospital at damaged rooftop equipment (Figure 4-124), and at areas where the roof membrane blew off (Figures 4-125 and 4-126) and where it was punctured. The roof failure shown in Figure 4-126 was caused by an inadequately attached edge nailer anchored to the brick wall. Failure of the nailer caused a progressive lifting and peeling of the roof membrane. Gutters and downspouts were blown off and a few windows were broken. The elevator penthouse roof was damaged at the psychiatric hospital (Figure 4-127) and the MOBs (Figure 4-125).

**Figure 4-124:** This hospital had a substantial amount of rooftop ductwork. Ductwork and fan units were damaged in several locations (see inset). Some of the windows in this area were also broken. Note the missing downspout (yellow arrow).

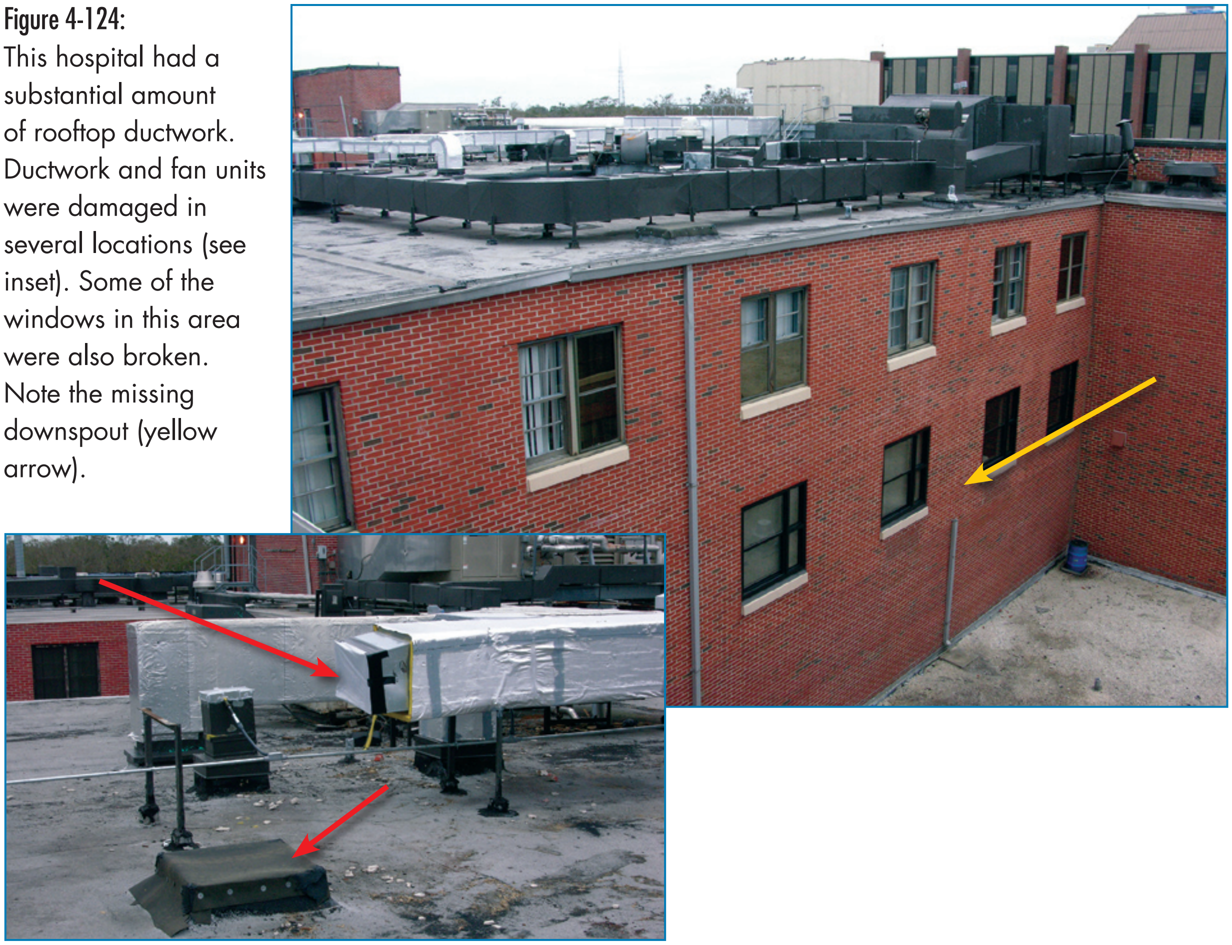
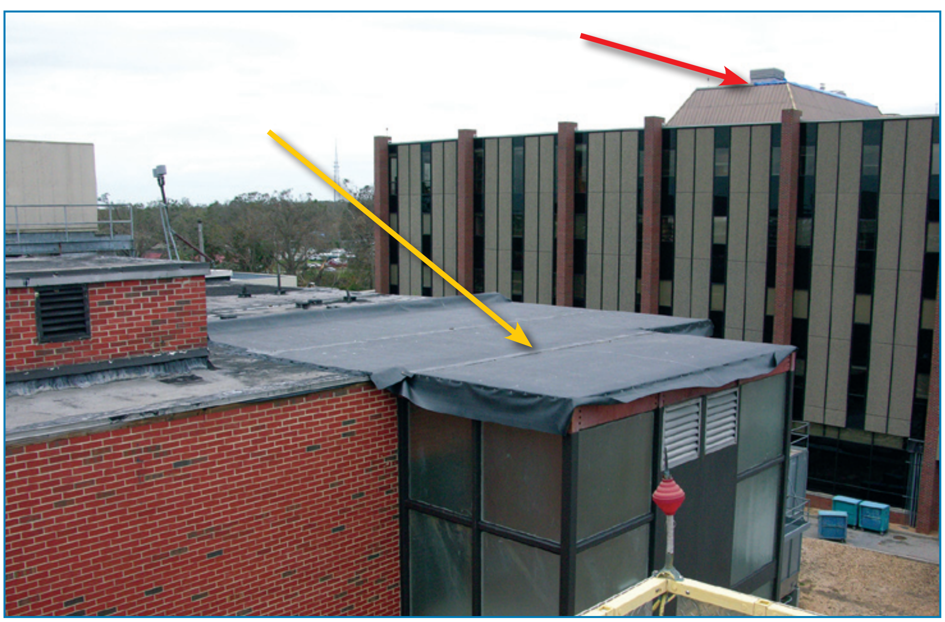


**Figure 4-125:** The roof covering blew off – an emergency roof covering had been installed (yellow arrow). Note the damaged MOB penthouse beyond (red arrow).



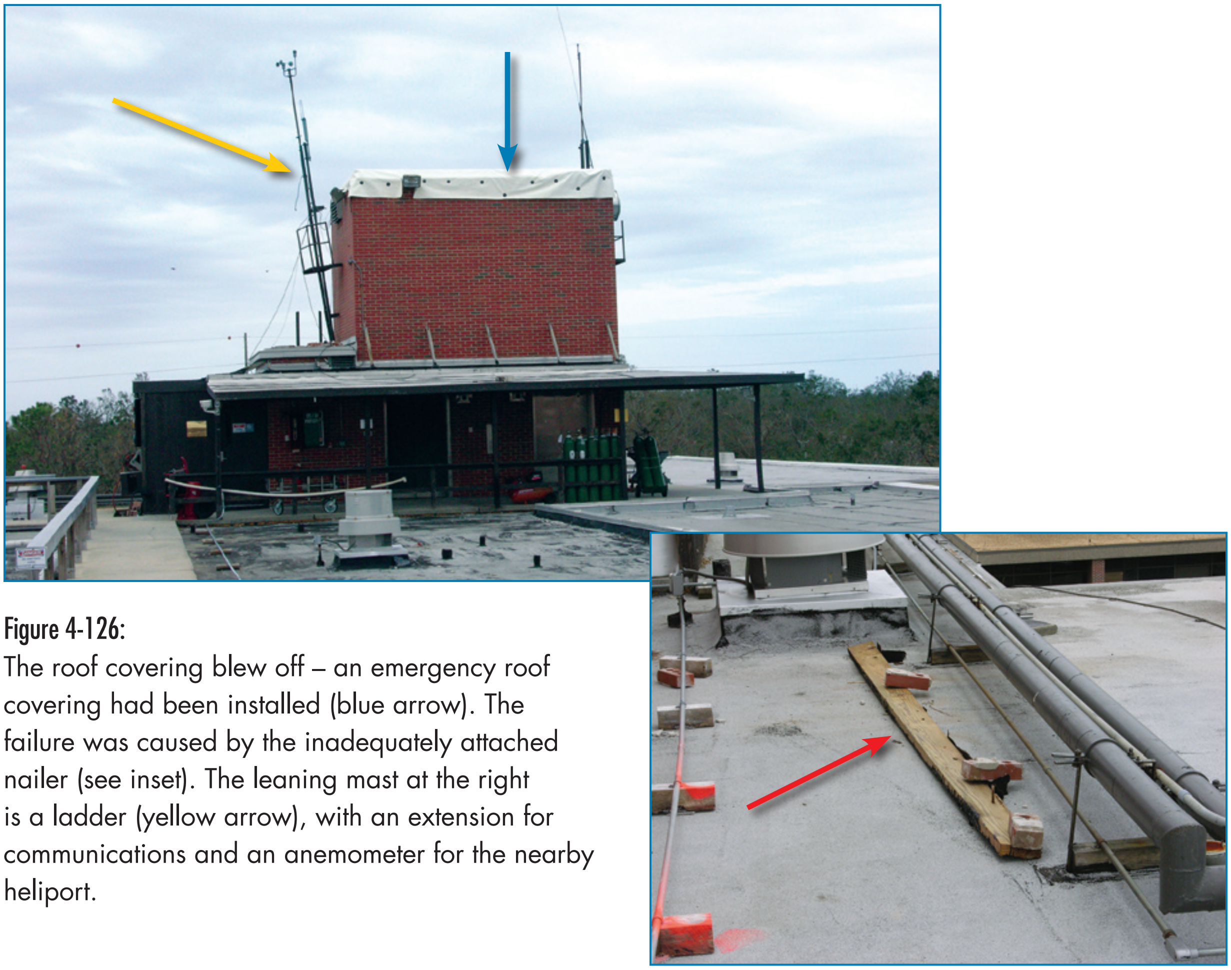


Figure 4-126:
The roof covering blew off – an emergency roof covering had been installed (blue arrow). The failure was caused by the inadequately attached nailer (see inset). The leaning mast at the right is a ladder (yellow arrow), with an extension for communications and an anemometer for the nearby heliport.

Figure 4-127:
An emergency roof covering had been installed over the elevator penthouse at the psychiatric hospital.

## 4.5 BEST PRACTICES IN TORNADO-PRONE REGIONS

Strong and violent tornadoes may reach wind speeds substantially greater than those recorded in the strongest hurricanes. The wind pressures that these tornadoes can exert on a building are tremendous, and far exceed the minimum pressures derived from building codes.

Strong and violent tornadoes can generate very powerful missiles. Experience shows that large and heavy objects, including vehicles, can be hurled into buildings at high speeds. The missile sticking out of the roof in the foreground of Figure 4-128 is a double 2-inch by 6-inch wood member. The portion sticking out of the roof is 13 feet long. It penetrated a ballasted ethylene propylene diene monomer (EPDM) membrane, approximately 3 inches of polyisocyanurate roof insulation, and the steel roof deck. The missile lying on the roof just beyond is a 2-inch by 10-inch by 16-foot long wood member.

**Figure 4-128:**
A violent tornado showered the roof with missiles. (Oklahoma, 1999)

Besides the case studies presented in Sections 4.5.1 and 4.5.2, there is little documentation regarding tornado-induced damage to hospitals. Most of the damage reports on critical facilities pertain to schools because schools are the most prevalent type of critical facilities and, therefore, are more likely to be struck. A 1978 report prepared for the Veterans Administration[17] identified four hospitals that were struck by tornadoes between 1973 and 1976. Table 4-2 (taken from that report) further illustrates the effects tornados can have on hospitals.

Table 4-2: Examples of Ramifications of Tornado Damage at Four Hospitals

| Location and Building Characteristics | Tornado Characteristics | Damage | Ramifications of Damage |
|---|---|---|---|
| Mountain View, Missouri (St. Francis Hospital). One-story steel frame with non-load bearing masonry exterior walls. | The tornado crossed over one end of the hospital. | Metal roof decking was blown off, some windows were broken, and rooftop mechanical equipment was displaced. | Patients were moved to undamaged areas of the hospital. |
| Omaha, Nebraska (Bishop Bergen Mercy Hospital). Five-story reinforced concrete frame. | Maximum wind speed estimated at 200 mph. Proximity to hospital not documented. | Windows were broken, and rooftop mechanical equipment was damaged and displaced. Communications and electrical power were lost (emergency generators provided power). | A few minor cuts; "double walled corridors" provided protection for patients and staff. Some incoming emergency room patients (injured elsewhere in the city) were rerouted to other hospitals. Loss of communications hampered the rerouting. |
| Omaha, Nebraska (Bishop Bergen Mercy Hospital – Ambulatory Care Unit). One-story load bearing CMU walls with steel joists. | See above. | The building was a total loss due to wall and roof collapse. | Patients were evacuated to the first floor of the main hospital when the tornado watch was issued. |
| Corsicana, Texas (Navarro County Memorial Hospital). Five-story reinforced concrete frame with masonry non-load bearing walls in some areas and glass curtain walls. | The tornado was very weak. | Many windows were broken by aggregate from the hospital's built-up roofs. Intake duct work in the penthouse collapsed. | Two people in the parking lot received minor injuries from roof aggregate. Electrical power was lost for 2 hours (emergency generators provided power). |
| Monahans, Texas (Ward Memorial Hospital). One-story load bearing CMU walls with steel joists. Some areas had metal roof deck and others had gypsum deck. | The tornado passed directly over the hospital, with maximum wind speed estimated at 150 mph. | The roof structure was blown away on a portion of the building (the bond beam pulled away from the wall). Many windows were broken. Rooftop mechanical equipment was damaged. | |

17 *A Study of Building Damage Caused by Wind Forces*, McDonald, J.R. and Lea, P.A, Institute for Disaster Research, Texas Tech University, 1978.

In this manual, the term "tornado-prone regions" refers to those areas of the United States where the number of recorded F3, F4, and F5 tornadoes per 3,700 square miles is 6 or greater per year (see Figure 4-129). However, an owner of a hospital may decide to use other frequency values (e.g., 1 or greater, 16 or greater, or greater than 25) in defining whether the hospital is in a tornado-prone area. In this manual, tornado shelters are recommended for all hospitals in tornado-prone regions.

Where the frequency value is 1 or greater, and the hospital does not have a tornado shelter, the best available refuge areas should be identified, as discussed at the end of this Section.

For hospitals located in tornado-prone regions (as defined in the text box), the following are recommended:

- Incorporate a shelter within the facility to provide occupant protection. For shelter design, FEMA 361 criteria are recommended.
- For interior non-load-bearing masonry walls, see the recommendations given in 4.3.3.5.
- Brick veneer, aggregate roof surfacing, roof pavers, slate, and tile cannot be effectively anchored to prevent them from becoming missiles if a strong or violent tornado passes near a building with these components. To reduce the potential number of missiles, and hence reduce the potential for building damage and injury to people, it is recommended that these materials not be specified for hospitals in tornado-prone regions.
- To minimize disruption from nearby weak tornadoes and from strong and violent tornados that are on the periphery of a hospital, the following are recommended:
    1) For the roof deck, exterior walls, and doors, follow the recommendations given in Sections 4.3.2.1, 4.3.3.2, and 4.3.3.6.
    2) For exterior glazing, specify laminated glass window assemblies that are designed to resist the test Missile E load specified in ASTM E 1996, and are tested in accordance with ASTM E 1886. Note that missile loads used for designing tornado shelters significantly exceed the missile loads used for designing glazing protection in hurricane-prone regions. Missiles from a strong or violent tornado passing near the facility could penetrate the laminated glazing and result in injury or interior damage. Therefore, to increase occupant safety, even when laminated glass is specified, the facility should also incorporate a shelter as recommended above.

It is recommended that hospitals have a National Oceanic and Atmospheric Administration (NOAA) weather radio, so that they will be aware of tornado watches and warnings. It is also recommended that hospitals have a plan to distribute notice of watches and warnings received via the radio to hospital staff.

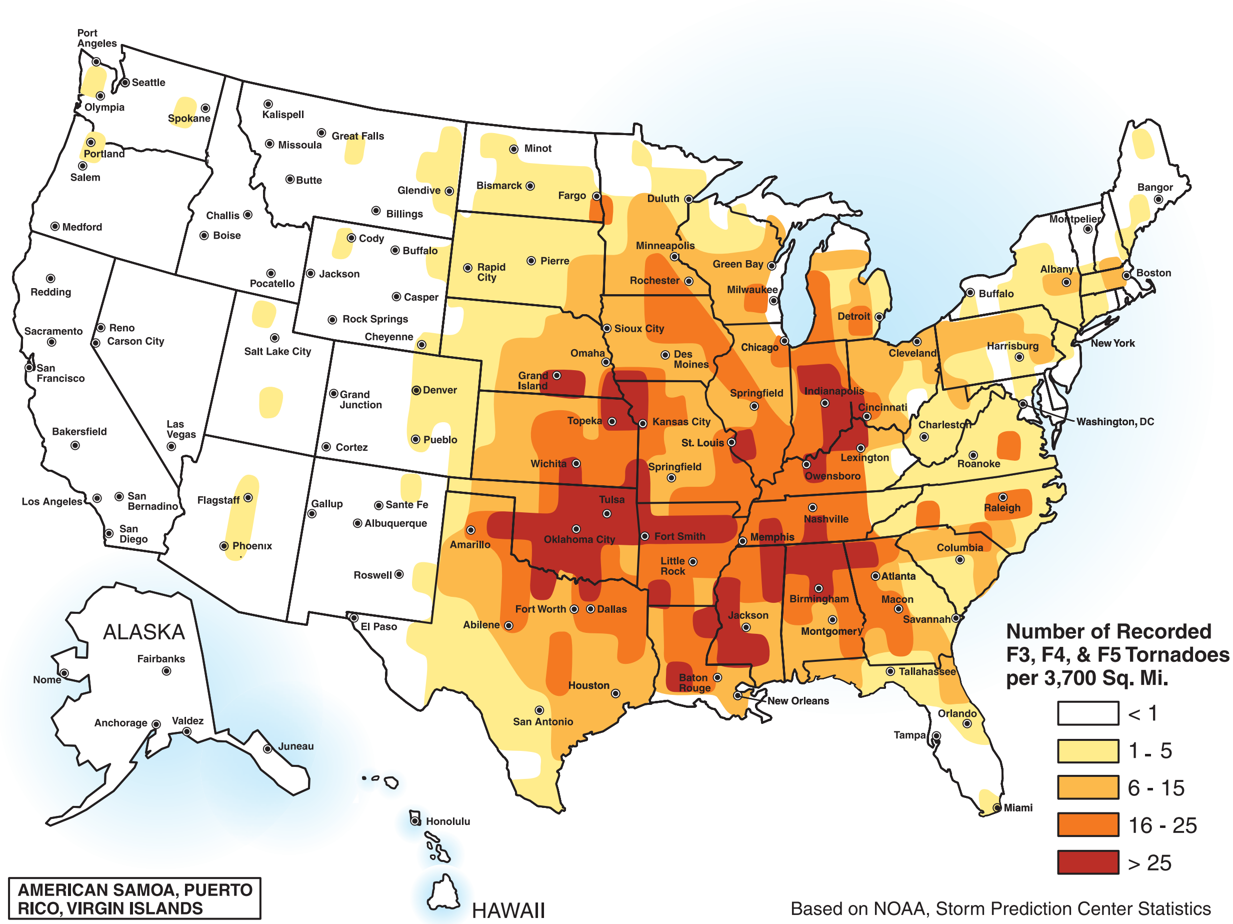



**Figure 4-129:** Frequency of recorded F3, F4, and F5 tornadoes (1950-1998)

## Existing Hospitals without Tornado Shelters

Where the number of recorded F3, F4, and F5 tornadoes per 3,700 square miles is one or greater (see Figure 4-129), the best available refuge areas should be identified if the hospital does not have a tornado shelter. FEMA 431, *Tornado Protection, Selecting Refuge Areas in Buildings* provides useful information for building owners, architects, and engineers who perform evaluations of existing facilities.

To minimize casualties in hospitals, it is very important that the best available refuge areas be identified by a qualified architect or engineer.[18] Once identified, those areas need to be clearly marked so that occupants can reach the refuge areas without delay. Building occupants should not wait for the arrival of a tornado to try to find the best available refuge area

18 It should be understood that the occupants of a "best available refuge area" are still vulnerable to death and injury if the refuge area was not specifically designed as a tornado shelter.

in a particular facility; by that time, it will be too late. If refuge areas have not been identified beforehand, occupants will take cover wherever they can, frequently in very dangerous places. Corridors, as shown in Figure 4-142, sometimes provide protection, but they can also be death traps.

Retrofitting a shelter space inside an existing hospital can be very expensive. An economical alternative is an addition that can function as a shelter as well as serve another purpose. This approach works well for smaller facilities. For very large facilities, constructing two or more shelter additions should be considered in order to reduce the time it takes to reach the shelter (often there is ample warning time, but sometimes an approaching tornado is not noticed until a few minutes before it strikes). This is particularly important for hospitals because of the difficulty of accommodating patients with different medical needs.

### 4.5.1 THE CASE OF KIOWA COUNTY MEMORIAL HOSPITAL, GREENSBURG, KANSAS

The case of Kiowa County Memorial Hospital illustrates damage that is indicative of smaller, older facilities that are struck by strong tornadoes. The hospital is a 28-bed, one-story facility. The original hospital comprised three separate buildings (two of these are shown in Figure 4-131): a patient wing, a kitchen facility, and an equipment building, and was constructed in 1950. Additions were built in 1965 and 1982. A separate, ambulance garage was built prior to 1979, and a separate pre-engineered metal storage building was added in 2006. The original buildings had precast twin-tee roof structures and at the time of the storm, they had aggregate ballasted single-ply membrane roof systems. The additions all had different structural systems. The 1965 patient wing addition had a concrete topping slab over metal form deck over steel roof joists. The 1982 addition, which housed the emergency room, semi-intensive care, operating room, MRI, lab, medical records, and business offices, had a plywood roof deck over wood joists. The ambulance garage had a precast twin-tee roof structure.

Except for the storage building, the majority of the exterior walls were brick veneer over unreinforced CMU. A finished basement was built under portions of the 1965 and 1982 additions (the two basements were not interconnected).

Figure 4-130 shows the site plan.

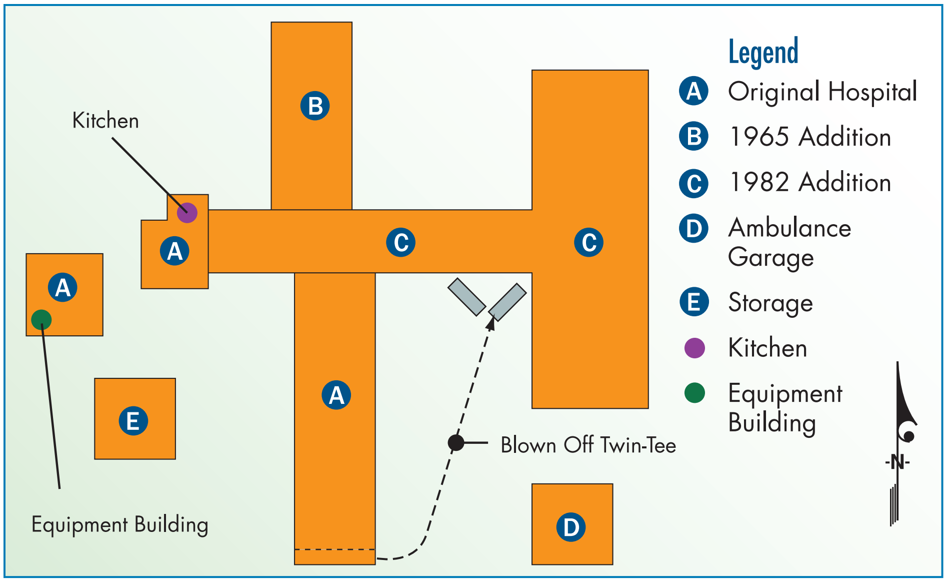



**Figure 4-130:** Site Plan

The hospital was struck by a tornado in 2007. The National Weather Service rated a portion of the track as an EF5 (with an estimated peak gust speed in excess of 200 mph). At the hospital site, the damage was indicative of an EF3 (with a speed between 136 and 165 mph). The 2005 edition of ASCE 7 lists the design wind speed for this location as 90 mph. Therefore, the speeds at this site were well above current design conditions.

**Figure 4-131:** The building housing the generator is shown by the yellow arrow. The kitchen facility is shown by the blue arrow. The red arrow shows the collapsed storage building.

Using the *Damage Indicators in the Enhanced Fujita Scale* (EF-Scale) for the main portion of the hospital, the *Degree of Damage* (DOD) indicated an expected wind speed during the tornado of 142 mph (with lower and upper bounds ranging from 119 to 163 mph). Failure analysis of the precast twin-tee that blew off the hospital indicated that a speed of approximately 147 mph was needed to blow off the tee, and a speed of approximately 193 mph was needed to toss it the 80 feet that it traveled.

The DOD at the pre-engineered storage building indicated an expected wind speed of 155 mph (with lower and upper bounds ranging from 132 to 178 mph).

Thus, the DOD of the hospital, the DOD of the storage building and the failure analysis of tee blow off indicate essentially the same estimated speed (142, 147, and 155 mph). The upper bound values of the DODs (163 and 178 mph) are lower than the 193 mph speed that was calculated to have tossed the tee. Based on the EF-Scale DODs, the 193 mph speed appears to be high.

One of the precast twin-tees from the original building blew off and flew approximately 80 feet (Figures 4-132 and 4-133). Where the tees rested on the bearing wall, steel bearing plates were embedded in the tee's beams, and bearing plates were embedded on top of the wall. At the wall in the foreground of Figure 4-132, the bearing plates had not been welded together. Hence, at that end of the tee, no uplift resistance was provided other than the tee's dead load. At the opposite bearing wall, the bearing plates were welded, but the bolts anchoring the plates to the wall failed in tension as the tee lifted. Both of the bearing plates had two small anchor bolts (about $^{3}/_{8}$-inch diameter).

**Figure 4-132:**
View of the end of the patient wing where the twin-tee blew off. Note the missing window.

**Figure 4-133:**
The missing tee shown in Figure 4-132 landed about 80 feet away (red oval). The red arrows show tees that were blown from the ambulance garage. Note the missing wood roof structure on the 1982 addition (yellow arrow).

The hospital complex was struck with a very large number of missiles. Virtually all of the hospital's exterior glazing was broken. Figure 4-134 shows a damaged door at the kitchen facility. A piece of built-up roof (BUR) membrane struck the right door. Although the doors were out-swinging, the missile pushed the door inward. The lower right hinge was broken, and the right side of the door frame buckled and pulled from the rough opening. The laminated glass in the door was broken, but remained in place.

**Figure 4-134:**
The BUR missile (red arrow) struck the right door. Missiles also punctured the siding and wood sheathing (red oval).

Aggregate from the ballasted single-ply membrane roofs broke several windows (Figure 4-135), and pieces of the large aggregate ($1\frac{1}{2}$-inches in diameter, nominal) were found inside the building. Windows were also broken by 2x wood framing (Figure 4-136).


Figure 4-135:
All six panes of glass were broken. The craters shown in the right center pane and at the vehicle windshield were caused by the large aggregate blown from the ballasted single-ply membranes.

Figure 4-136:
A large missile (2x framing) penetrated this patient room. Note the debris on the bed in the inset (the arrow shows the same 2x missile).

Figure 4-137 illustrates an opening through the entire exterior wall.

**Figure 4-137:**
A missile impact created an opening in the brick veneer and unreinforced CMU.

The building shown in Figure 4-131 (yellow arrow) and in Figure 4-138 housed the emergency generator. The sectional door collapsed and allowed wind-borne debris to strike the generator. All window panes in the wall adjacent to the sectional door were broken (see inset at Figure 4-138). The wall louver adjacent to the window, which served the generator room, escaped damage.

There was no apparent structural damage to the 1965 addition. However, the unreinforced brick/CMU parapet shown in Figure 4-139 fell onto the roof, rather than in the other direction, where it would have blocked the entry and possibly could have caused injuries. Virtually all of the exterior windows were broken (see Figures 4-135 and 4-136). The roof insulation and aggregate-ballasted single-ply roof membrane were blown off. The wood roof structure blew off the majority of the 1982 addition (Figures 4-133 and 4-140), and virtually all of the exterior windows were broken.

The precast twin-tees on the ambulance garage blew off and landed against the wall of the 1982 addition (Figures 4-133 and inset at 4-141). The garage door and virtually all of the exterior unreinforced brick/CMU bearing walls collapsed (Figure 4-141). Where the tees rested on the bearing wall, steel bearing plates were embedded in the tee's beams. However, bearing plates had not been embedded on top of the support walls. Rather, where the tee's beams rested on the wall, a piece of roof membrane had been installed between the beams and the wall. Hence, at the ends of the tees, no uplift resistance was provided other than the tee's dead load.

**Figure 4-138:** The sectional door (red arrow) at the generator building was blown in and windows were broken by debris.

**Figure 4-139:** Collapsed unreinforced masonry parapet. Note the broken windows.

There were 20 patients and 10 staff in the facility when the tornado struck around 9:45 p.m. Fortunately, the staff was aware of the tornado warning that was issued by the National Weather Service. Patients and staff took refuge in the basement of the 1965 addition per the hospital's tornado plan. Because of the extensive structural and non-structural damage, it was necessary to completely evacuate the hospital after the storm. Evacuation was completed by around 2:45 a.m. (about 5 hours after the tornado). None of the occupants were injured during the storm or evacuation. The ambulance shown in Figure 4-141 was not usable because of missile damage. Even though some portions of the facility could be salvaged, significant demolition and reconstruction will be necessary.

**Figure 4-140:**
Loss of the wood roof structure at the 1982 addition.

**Figure 4-141:**
View of the collapsed ambulance garage. The twin-tees (red arrows) flew to the left, as shown in the inset.

The loss of life and avoidance of injuries was attributed to three factors. 1) A tornado warning was issued by the National Weather Service about 20 minutes before the tornado struck, and the hospital's staff was aware of the warning. 2) The hospital had a tornado evacuation plan and there was sufficient time to execute the plan. 3) Although it is believed that the basement was not specifically designed as a tornado shelter, it provided a safe area of refuge for patients and staff. For hospitals located in tornado-prone regions, the experience from this tornado demonstrates the importance of having a pre-identified, best available refuge area (or preferably a FEMA 361-compliant shelter). Although small interior rooms and corridors sometimes provide adequate protection during tornadoes, unless specifically designed as a tornado shelter, they often provide inadequate protection, as shown in Figure 4-142.

**Figure 4-142:** View of a main corridor in the 1982 addition

It was determined that with minimal work, the basement under the 1965 addition could be used as an interim, best available refuge area for the city. In the weeks and months following the storm, several hundred people would be in the city performing demolition, salvaging personal items, and conducting reconstruction. Much of this work would occur during the time of year when tornado activity is high. Hence, although severely damaged, a portion of the hospital continued to serve the community by providing an interim refuge area.

The damage investigation of this facility validates several of the recommendations provided in Section 4.5, summarized below:

- Incorporate a tornado shelter within the facility.
- Don't use aggregate roof surfacing.
- Use roof decks, exterior walls, and doors as recommended in sections 4.3.2.1, 4.3.3.2, and 4.3.3.6.
- Use laminated glass window assemblies that are designed to resist the test Missile E.

## 4.5.2 THE CASE OF SUMTER REGIONAL HOSPITAL, AMERICUS, GEORGIA

The previous case study reported on a smaller, older hospital that was struck by a tornado. The case of Sumter Regional Hospital illustrates the performance of a much larger and newer hospital. This hospital is a 143-bed, four-story facility built in 1953, and expanded in 1975, 1983, and 1999. The 1999 addition had a cast-in-place concrete roof deck. All of the other buildings had steel roof decks. Roof coverings included single-ply membranes (exposed and aggregate-ballasted) and aggregate surfaced built-up. Exterior walls included brick veneer (over unreinforced CMU and over steel studs) and EIFS over steel studs.


**Figure 4-143:**
Aerial view of the facility after it was struck by the tornado. The red arrow indicates the general direction of the tornado. The blue arrow shows the 1953 building, and the yellow arrow shows the 1999 building. The 1975 and 1983 additions are adjacent to and behind the 1953 and 1999 buildings.

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The hospital was struck by a tornado in 2007. The National Weather Service rated a portion of the track as an EF3 (with an estimated peak gust speed between 136 and 165 mph). At the hospital site, the damage was indicative of an EF2 (with a speed between 111 and 135 mph). The 2005 edition of ASCE 7 lists the design wind speed for this location as 90 mph. Therefore, the speeds at this site were well above current design conditions.

Using the Damage Indicators in the Enhanced Fujita Scale (EF-Scale), the Degree of Damage (DOD) at the hospital indicated an expected wind speed during the tornado of 131 mph (with lower and upper bounds ranging from 110 to 152 mph).

As the tornado approached the southwest side of the hospital, numerous tree branches from trees in front of the hospital were thrown against the building. Missiles broke virtually all of the glass in the southwest walls (Figures 4-144 and 4-145), and missiles penetrated the EIFS and landed inside the building. Roof decking and steel joists were blown off of portions of the 1953 building, and the roof membrane was blown off of several different areas of the facility.

The right (curved) portion of the building in Figure 4-144 is the 1999 addition. This portion of the first floor housed waiting and exam rooms. Offices were on the second floor, and medical offices were on the third floor. Figures 4-144 and 4-146 also show part of the 1953 building. Offices were on the first floor, and patient rooms were on the second and third floors.

**Figure 4-144:** The 1999 addition is on the right, and the 1953 building is to the left. Virtually all of the glass on these facades was broken.

**Figure 4-145:** One window frame was blown away (red circle). The EIFS was penetrated by many missiles, and in some areas, the entire wall (except the studs) was blown away (arrows).

**Figure 4-146:** Several of the window frames were blown away, along with some of the brick veneer (1999 addition).

Broken glass showered the rooms along the exterior walls. The breach of the building envelope allowed strong winds to enter the rooms and corridors, which led to the collapse of suspended acoustical ceilings and light fixtures. Figure 4-147 illustrates the extent of the interior damage.

Figure 4-147:
Glass shards and other debris in the lobby area housing retail shops and offices.

Damage also occurred on other facades, including collapse of a glass curtain wall and a portion of a brick veneer/unreinforced CMU wall (Figure 4-148). A large unreinforced brick chimney collapsed on a roof, and a large rooftop air handling unit (20 x 7 x 9 feet) was shifted several feet. A substantial amount of water entered the building at various places where the envelope was breached.

Much of the aggregate ballast ($1\frac{1}{2}$-inch nominal diameter) was blown from the roof, and broke numerous vehicle windows in the parking lot.

**Figure 4-148:** Collapsed brick veneer/CMU wall at a mechanical room. The cast-in-place concrete wall (arrow) remained, but the brick veneer was blown away.

There were 54 patients in the facility when the tornado struck around 9:15 p.m. Staff was not aware of the approaching tornado until just before it struck. Most of the patients and newborn infants were moved into hallways as the tornado struck the building. Some remained in their beds during the few seconds of the tornado impact. People were injured, but none seriously. Because of the extensive damage, it was necessary to completely evacuate the hospital after the storm. Evacuation was completed by around 2:00 a.m. (about 5 hours after the tornado).

Within a couple of days, an urgent care facility was temporarily set up in a tent. Temporary modular buildings were also brought in to provide space for an expanded array of healthcare services for the community. After approximately 3 months of study, it was decided to demolish the entire hospital complex and build a new facility. An interim facility was expected to be completed by the fall of 2007.

In addition to the impacts on delivery of healthcare to the community, the damage had potential impacts on the economy. The hospital had approximately 700 employees and was one of the largest employers in the county. Had there been significant interruptions in meeting payroll, or had it been decided to close the facility and rely on a hospital that was approximately 40 miles away, the loss of jobs would likely have been difficult on the community.

As with the previous case study, the damage investigation of this facility validates several of the recommendations provided in Section 4.5. In particular, this case study validates the recommendations pertaining to use of roof decks, exterior walls, and doors, as recommended in sections 4.3.2.1, 4.3.3.2, and 4.3.3.6, and the use of laminated glass window assemblies that are designed to resist the test Missile E. In those instances where there is little or no warning of an impending tornado strike, maintaining building envelope integrity is crucial to providing protection to patients and staff, and in minimizing disruption of services.

## 4.6 CHECKLIST FOR BUILDING VULNERABILITY OF HOSPITALS EXPOSED TO HIGH WINDS

The Building Vulnerability Assessment Checklist (Table 4-3) is a tool that can help in assessing the vulnerability of various building components during the preliminary design of a new building, or the rehabilitation of an existing building. In addition to examining design issues that affect vulnerability to high winds, the checklist also examines the potential adverse effects on the functionality of the critical and emergency systems upon which most critical facilities depend. The checklist is organized into separate sections, so that each section can be assigned to a subject expert for greater accuracy of the examination. The results should be integrated into a master vulnerability assessment to guide the design process and the choice of appropriate mitigation measures.

Table 4-3: Checklist for Building Vulnerability of Hospitals Exposed to High Winds

| Vulnerability Sections | Guidance | Observations |
|---|---|---|
| **General** | | |
| What is the age of the facility, and what building code and edition was used for the design of the building? | Substantial wind load improvements were made to the model building codes in the 1980s. Many buildings constructed prior to these improvements have structural vulnerabilities. Since the 1990s, several additional changes have been made, the majority of which pertain to the building envelope.<br><br>Older buildings, not designed and constructed in accordance with the practices developed since the early 1990s, are generally more susceptible to damage than newer buildings. | |

Table 4-3: Checklist for Building Vulnerability of Hospitals Exposed to High Winds (continued)

| Vulnerability Sections | Guidance | Observations |
|---|---|---|
| General (continued) | | |
| Is the hospital older than 5 years, or is it located in a zone with basic wind speed greater than 90 mph? | In either case, perform a vulnerability assessment with life-safety issues as the first priority, and property damage and interruption of service as the second priority. | |
| Site | | |
| What is the design wind speed at the site? Are there topographic features that will result in wind speed-up? | ASCE 7 | |
| What is the wind exposure on site? | Avoid selecting sites in Exposure D, and avoid escarpments and hills | |
| Are there trees or towers on site? | Avoid trees and towers near the facility. If the site is in a hurricane-prone region, avoid trees and towers near primary access roads. | |
| Road access | Provide two separate means of access. | |
| Is the site in a hurricane-prone region? | ASCE 7. If yes, follow hurricane-resistant design guidance. | |
| If in a hurricane-prone region, are there aggregate surfaced roofs within 1,500 feet of the facility? | Remove aggregate from existing roofs. If the buildings with aggregate are owned by other parties, attempt to negotiate the removal of the aggregate (e.g., consider offering to pay the reroofing costs). | |
| Architectural | | |
| Will the facility be used as a shelter? | If yes, refer to FEMA 361. | |
| Are there interior non-load-bearing walls? | Design for wind load. | |
| Are there multiple buildings on site in a hurricane-prone region? | Provide enclosed walkways between buildings that will be occupied during a hurricane. | |
| Are multiple elevators needed for the building? | Place elevators in separate locations served by separate penthouses. | |

| Vulnerability Sections | Guidance | Observations |
|---|---|---|
| Structural Systems | Section 4.3.2 | |
| Is a pre-engineered building being considered? | If yes, ensure the structure is not vulnerable to progressive collapse. If a pre-engineered building exists, evaluate to determine if it is vulnerable to progressive collapse. | |
| Is precast concrete being considered? | If yes, design the connections to resist wind loads. If precast concrete elements exist, verify that the connections are adequate to resist the wind loads. | |
| Are exterior load-bearing walls being considered? | If yes, design as MWFRS and C&C. | |
| Is an FM Global-rated roof assembly specified? | If yes, comply with FM Global deck criteria. | |
| Is there a covered walkway or canopy? | If yes, use "free roof" pressure coefficients from ASCE 7.Canopy decks and canopy framing members on older buildings often have inadequate wind resistance. Wind-borne debris from canopies can damage adjacent buildings and cause injury. | |
| Is the site in a hurricane-prone region? | A reinforced cast-in-place concrete structural system, and reinforced concrete or fully grouted and reinforced CMU walls, are recommended. | |
| Is the site in a tornado-prone region? | If yes, provide occupant protection. See FEMA 361. | |
| Do portions of the existing facility have long-span roof structures (e.g., a gymnasium)? | Evaluate structural strength, since older long-span structures often have limited uplift resistance. | |
| Is there adequate uplift resistance of the existing roof deck and deck support structure? | The 1979 (and earlier) SBC and UBC, and 1984 (and earlier) BOCA/NBC, did not prescribe increased wind loads at roof perimeters and corners. Decks (except cast-in-place concrete) and deck support structures designed in accordance with these older codes are quite vulnerable.The strengthening of the deck attachment and deck support structure is recommended for older buildings. | |

Table 4-3: Checklist for Building Vulnerability of Hospitals Exposed to High Winds (continued)

| Vulnerability Sections | Guidance | Observations |
|---|---|---|
| Structural Systems | Section 4.3.2 (continued) | |
| Are there existing roof overhangs that cantilever more than 2 feet? | Overhangs on older buildings often have inadequate uplift resistance. | |
| Building Envelope | Section 4.3.3 | |
| Exterior doors, walls, roof systems, windows, and skylights. | Select materials and systems, and detail to resist wind and wind-driven rain. | |
| Are soffits considered for the building? | Design to resist wind and wind-driven water infiltration. If there are existing soffits, evaluate their wind and wind-driven rain resistance. If the soffit is the only element preventing wind-driven rain from being blown into an attic space, consider strengthening the soffit. | |
| Are there elevator penthouses on the roof? | Design to prevent water infiltration at walls, roof, and mechanical penetrations. | |
| Is a low-slope roof considered on a site in a hurricane-prone region? | A minimum 3-foot parapet is recommended on low-slope roofs. | |
| Is an EOC, healthcare facility, shelter, or other particularly important hospital in a hurricane-prone region? | If yes, a very robust building envelope, resistant to missile impact, is recommended. | |
| Is the site in a tornado-prone region? | To minimize generation of wind-borne missiles, avoid the use of brick veneer, aggregate roof surfacing, roof pavers, slate, and tile. | |
| Are there existing sectional or rolling doors? | Older doors often lack sufficient wind resistance. | |
| Does the existing building have large windows or curtain walls? | If an older building, evaluate their wind resistance. | |
| Does the existing building have exterior glazing (windows, glazed doors, or skylights)? | If the building is in a hurricane-prone region, replace with impact-resistant glazing, or protect with shutters. | |
| Does the existing building have operable windows? | If an older building, evaluate its wind-driven rain resistance. | |
| Are there existing exterior non-load-bearing masonry walls? | If the building is in a hurricane- or tornado-prone region, strengthen or replace. | |

| Vulnerability Sections | Guidance | Observations |
|---|---|---|
| Building Envelope | Section 4.3.3 (continued) | |
| Are there existing brick veneer, EIFS, or stucco exterior coverings? | If the building is in a hurricane-prone region, evaluate attachments. To evaluate wind resistance of EIFS, see ASTM E 2359 (2006). | |
| Are existing exterior walls resistant to wind-borne debris? | If the building is in a hurricane-prone region, consider enhancing debris resistance, particularly if dealing with an important hospital. | |
| Are there existing ballasted single-ply roof membranes? | Determine if they are in compliance with ANSI/SPRI RP-4. If non-compliant, take corrective action. | |
| Does the existing roof have aggregate surfacing, lightweight pavers, or cementitious-coated insulation boards? | If the building is in a hurricane- prone region, replace the roof covering to avoid blow-off. | |
| Does the existing roof have edge flashing or coping? | Evaluate the adequacy of the attachment. | |
| Does the existing roof system incorporate a secondary membrane? | If not, and if the building is in a hurricane-prone region, reroof and incorporate a secondary membrane into the new system. | |
| Does the existing building have a brittle roof covering, such as slate or tile? | If the building is in a hurricane-prone region, consider replacing with a non-brittle covering, particularly if it is an important hospital. | |
| Exterior-Mounted Mechanical Equipment | | |
| Is there mechanical equipment mounted outside at grade or on the roof? | Anchor the equipment to resist wind loads. If there is existing equipment, evaluate the adequacy of the attachment, including attachment of cowlings and access panels. | |
| Are there penetrations through the roof? | Design intakes and exhausts to avoid water leakage. | |
| Is the site in a hurricane-prone region? | If yes, place the equipment in a penthouse, rather than exposed on the roof. | |
| Exterior-Mounted Electrical and Communications Equipment | | |
| Are there antennae (communication masts) or satellite dishes? | If there are existing antennae or satellite dishes and the building is located in a hurricane-prone region, evaluate wind resistance. For antennae evaluation, see Chapter 15 of ANSI/TIA-222-G-2005. | |

Table 4-3: Checklist for Building Vulnerability of Hospitals Exposed to High Winds (continued)

| Vulnerability Sections | Guidance | Observations |
|---|---|---|
| Exterior-Mounted Electrical and Communications Equipment (continued) | | |
| Does the building have a lightning protection system? | See Sections 4.3.4.4 and 4.4.3.2 for lightning protection system attachment. For existing lightning protection systems, evaluate wind resistance, see Section 4.4.3.2. | |
| Municipal Utilities | | |
| Is the site in a hurricane-prone region? | See Section 4.3.5.1 for emergency and standby power recommendations. | |
| Is the emergency generator(s) housed in a wind- and debris-resistant enclosure? | If not, build an enclosure to provide debris protection in a hurricane-prone region. | |
| Is the emergency generator's wall louver protected from wind-borne debris? | If the building is in a hurricane-prone region, install louver debris impact protection. | |
| Is the site in a hurricane-prone region? | If yes, an independent water supply and alternative means of sewer service are recommended, independent of municipal services. | |

## 4.7 REFERENCES AND SOURCES OF ADDITIONAL INFORMATION

**Note:** FEMA publications may be obtained at no cost by calling (800) 480-2520, faxing a request to (301) 497-6378, or downloading from the library/publications section online at http://www.fema.gov.

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